===== SID '01 SHORT COURSE =====

(S-2)

Fundamentals of Active-Matrix Liquid-Crystal Displays

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Fundamentals of Active-Matrix Liquid-Crystal Displays

I. Introduction

II. Liquid Crystal Displays

III. Structure of Color TFT-LCDs

IV. Basic Operation Principles & Design of Color TFT-LCDs

V. Color TFT-LCD Fabrication Process

VI. Summary and Projections

I. Introduction

- What is Liquid Crystal ?
- Structure of L/C
- Alignment of L/C
- TN & STN Modes
- Normally White and Black Modes

What is Liquid Crystal ?

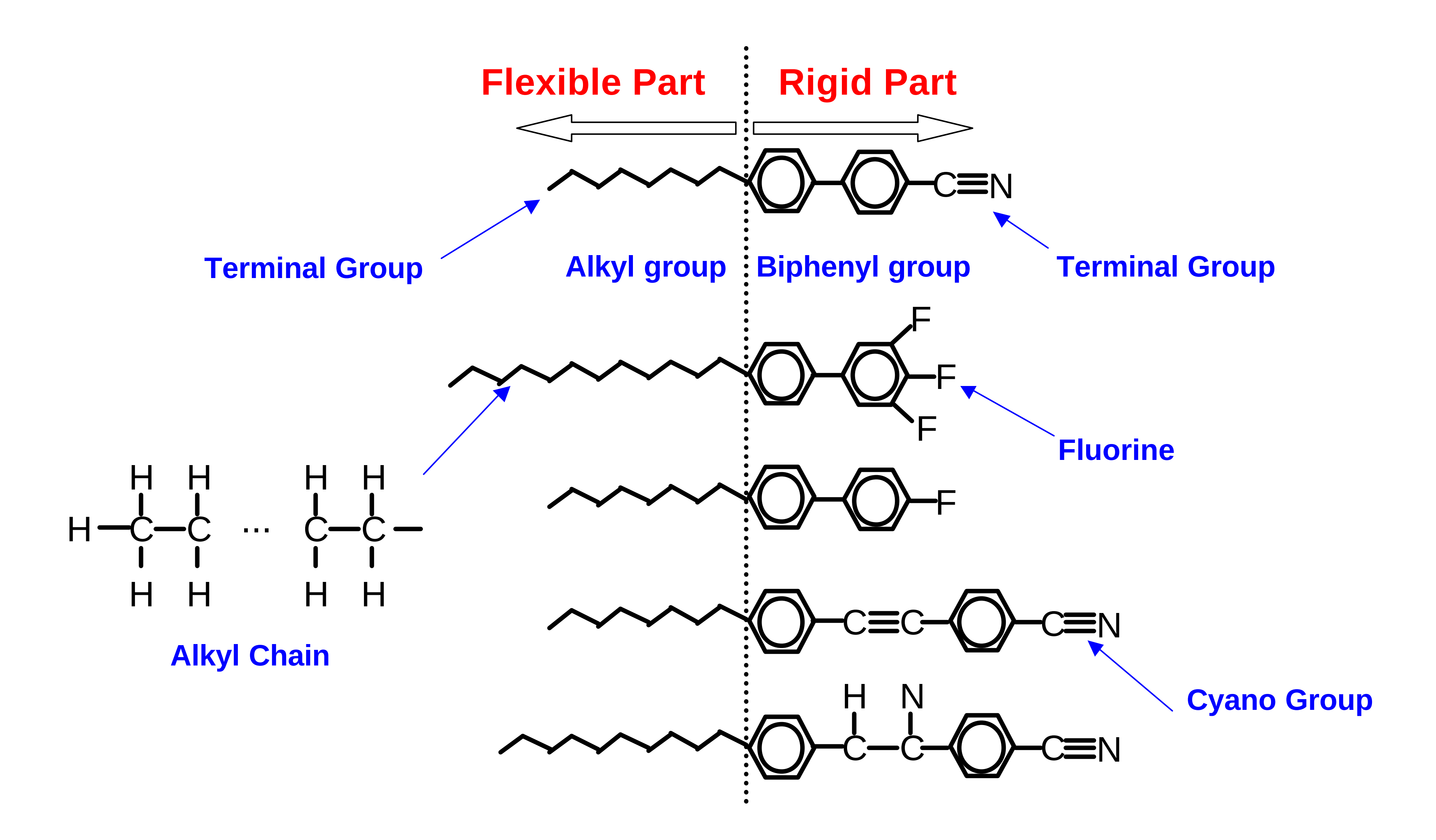


Figure 1. The structure of a L/C

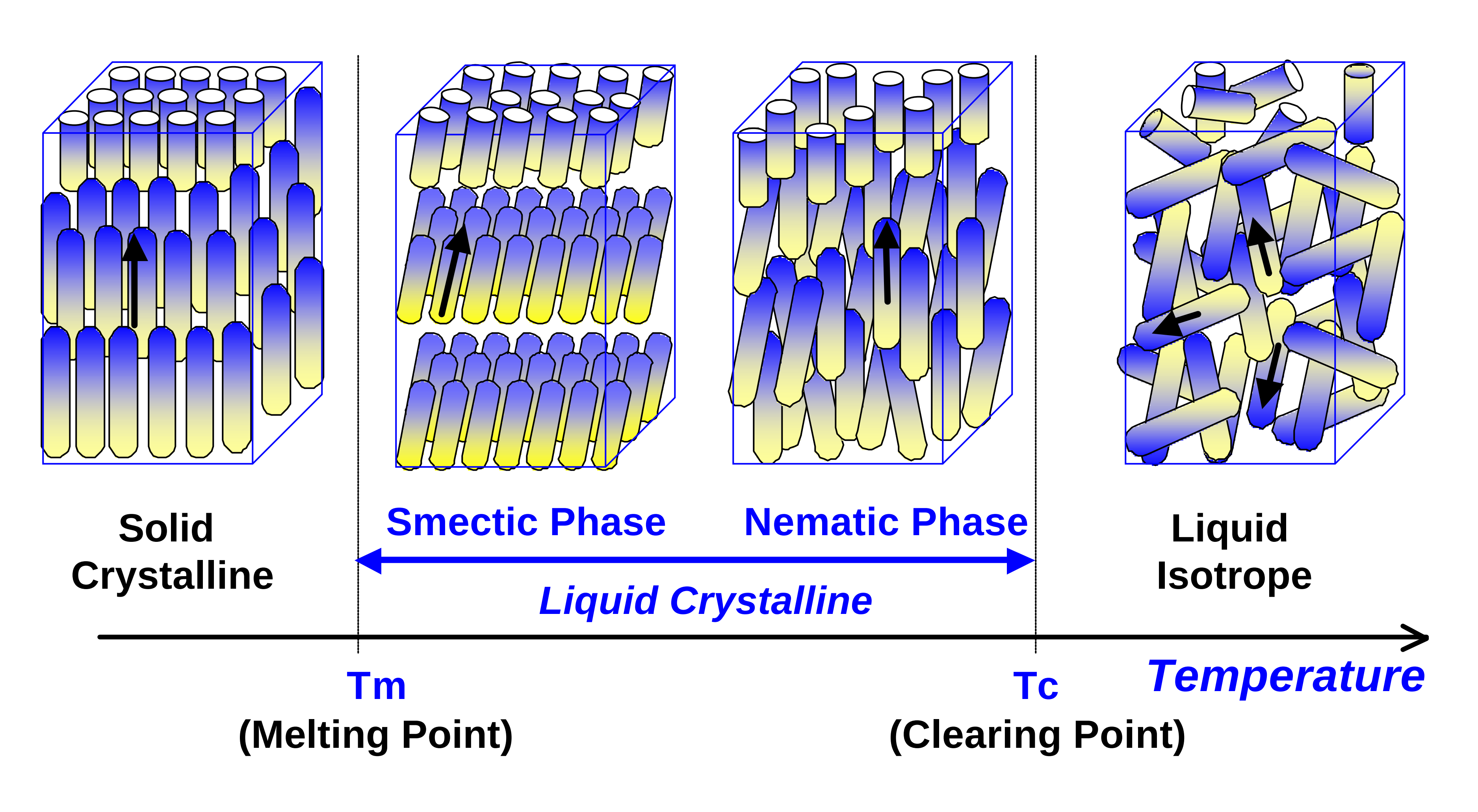
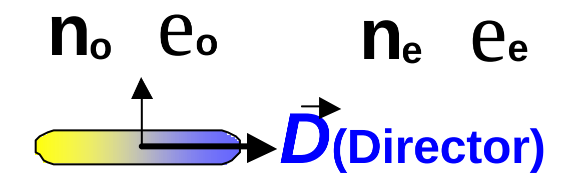


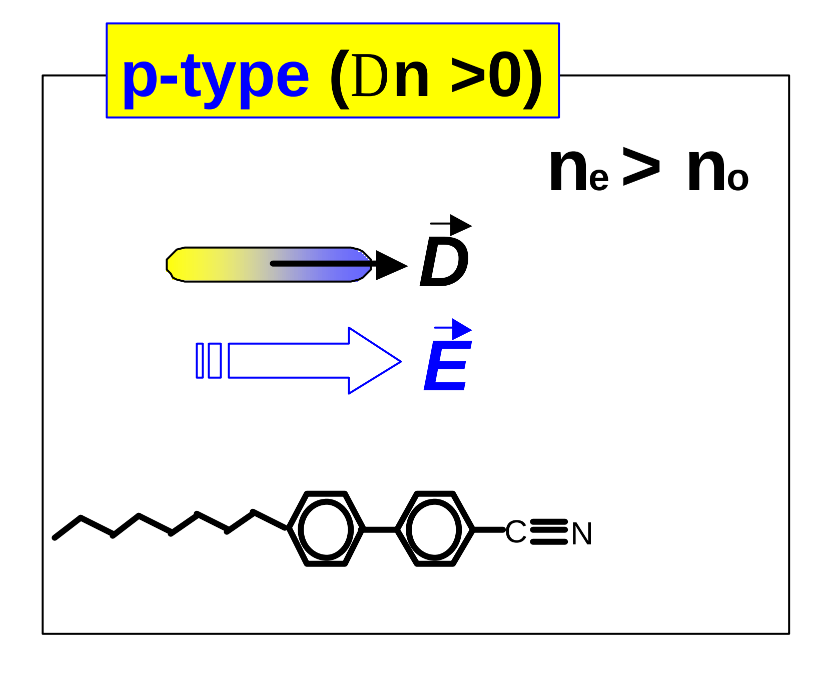
Figure 2. Phases of a Liquid Crystal

Structure of Liquid Crystal

Birefringence: $Dn = n_e - n_o$

Dielectric Anisotropy: $De = e_e - e_o$





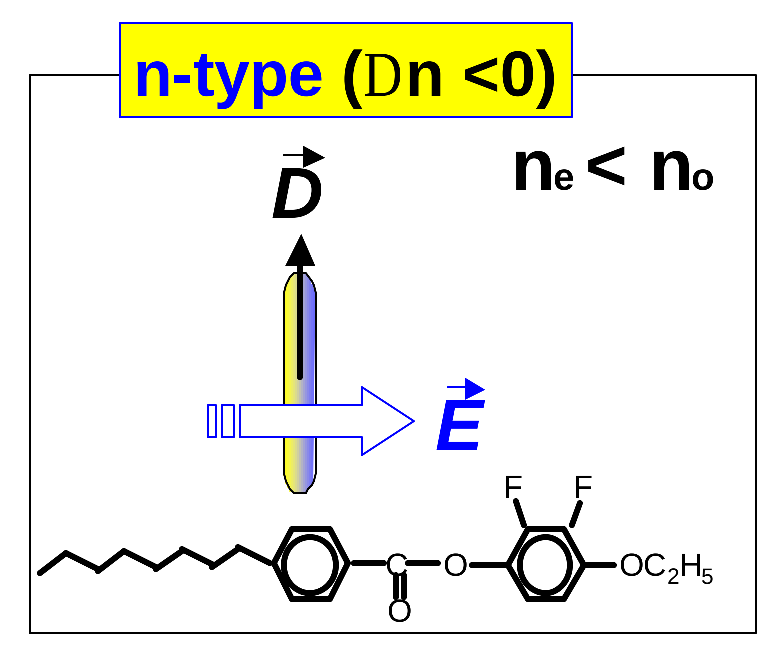


Figure 3. Anisotropy of a L/C

Intermolecular Attraction: Long Axis > Short Axis

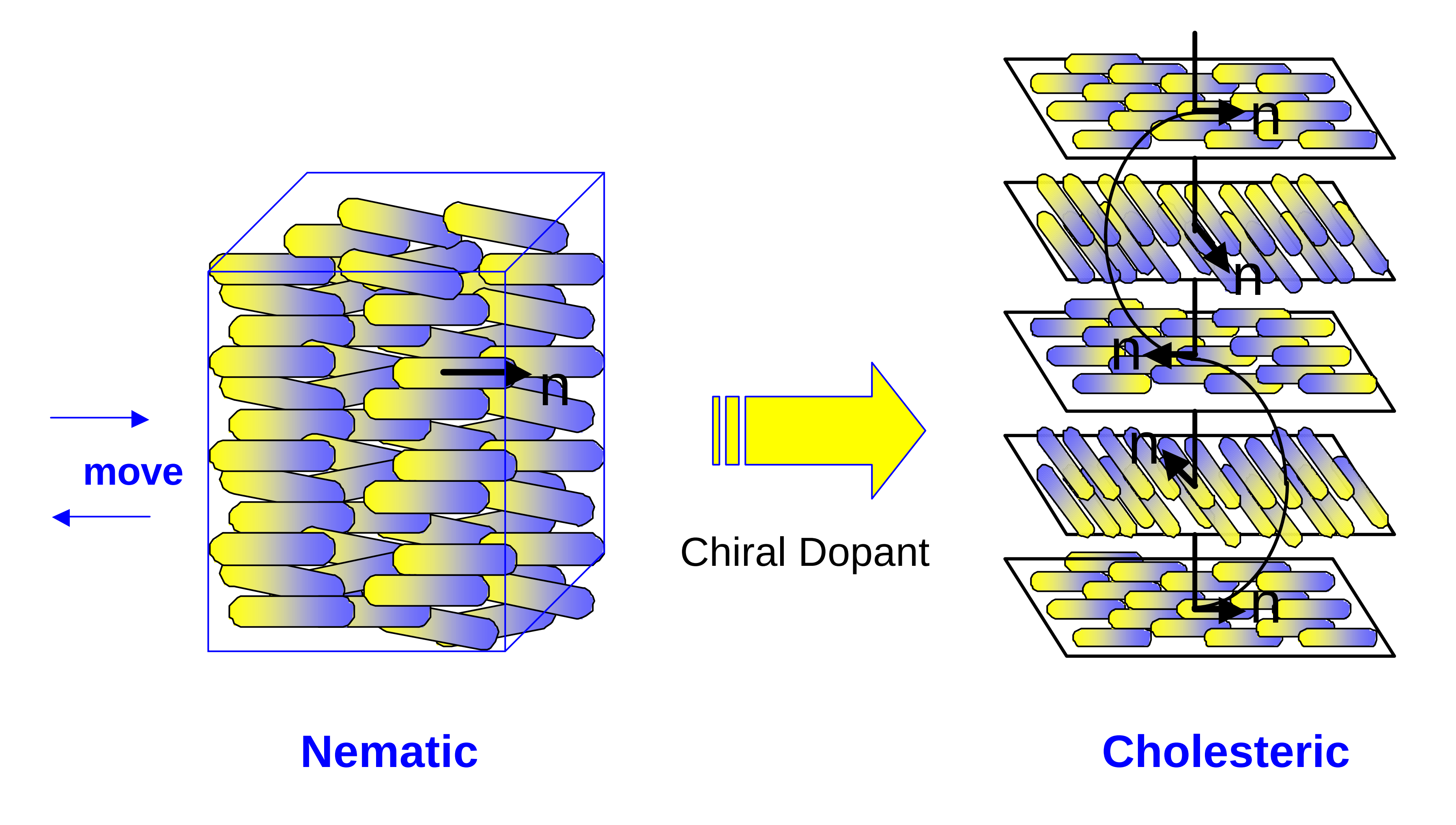


Figure 4. Types of liquid crystal phases

Intermolecular Attraction: Short Axis > Long Axis

Perpendicular to the layer

Tilted to the layer

u

u

move

Smetic A
(SmA)

Smetic C
(SmC)

Figure 5. Types of Liquid Crystal Phases

Alignment of Liquid Crystal

Interaction: L/C Molecule & Substrate

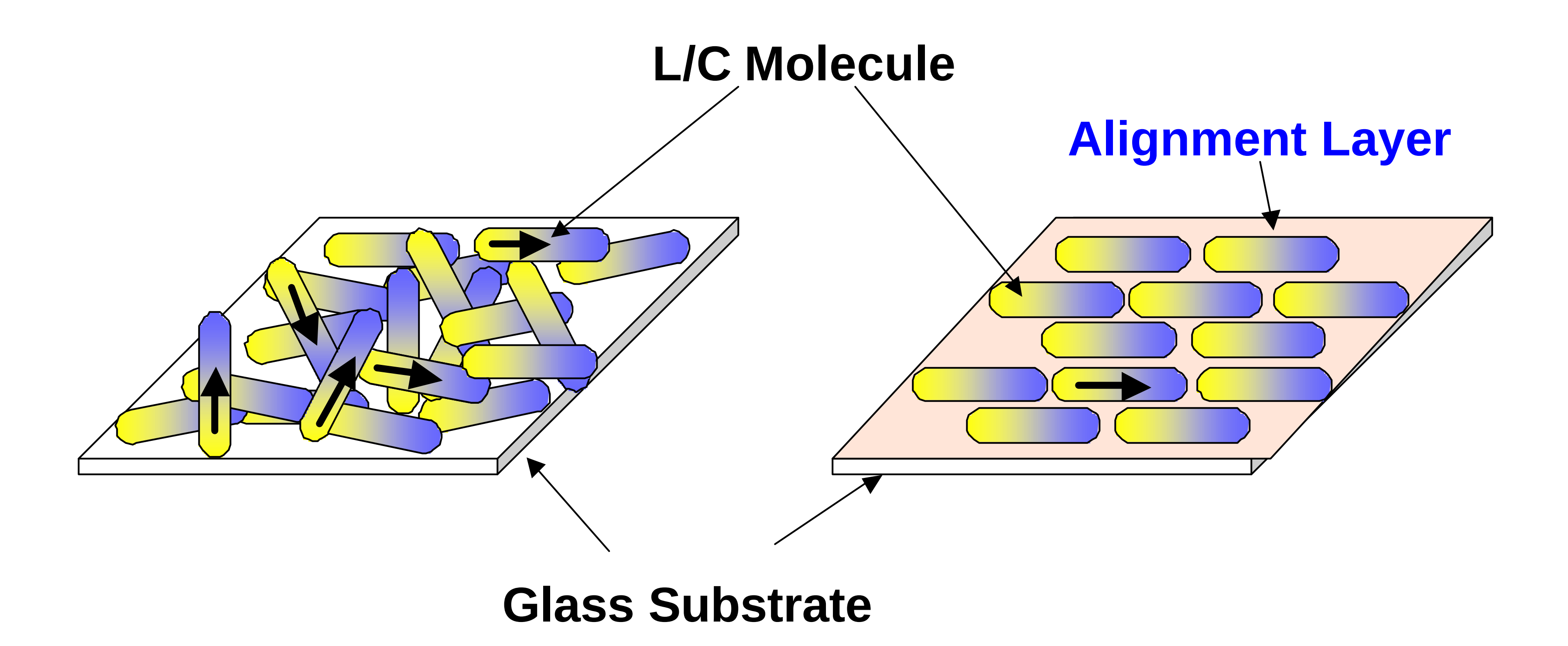


Figure 6. Liquid crystal alignment layer

TN and STN Modes

Mauguin's Condition for TN : Dn? p = Dn? d x 2p/Q > l

Retardation for TN: Dn? d = 0.3~0.5mm

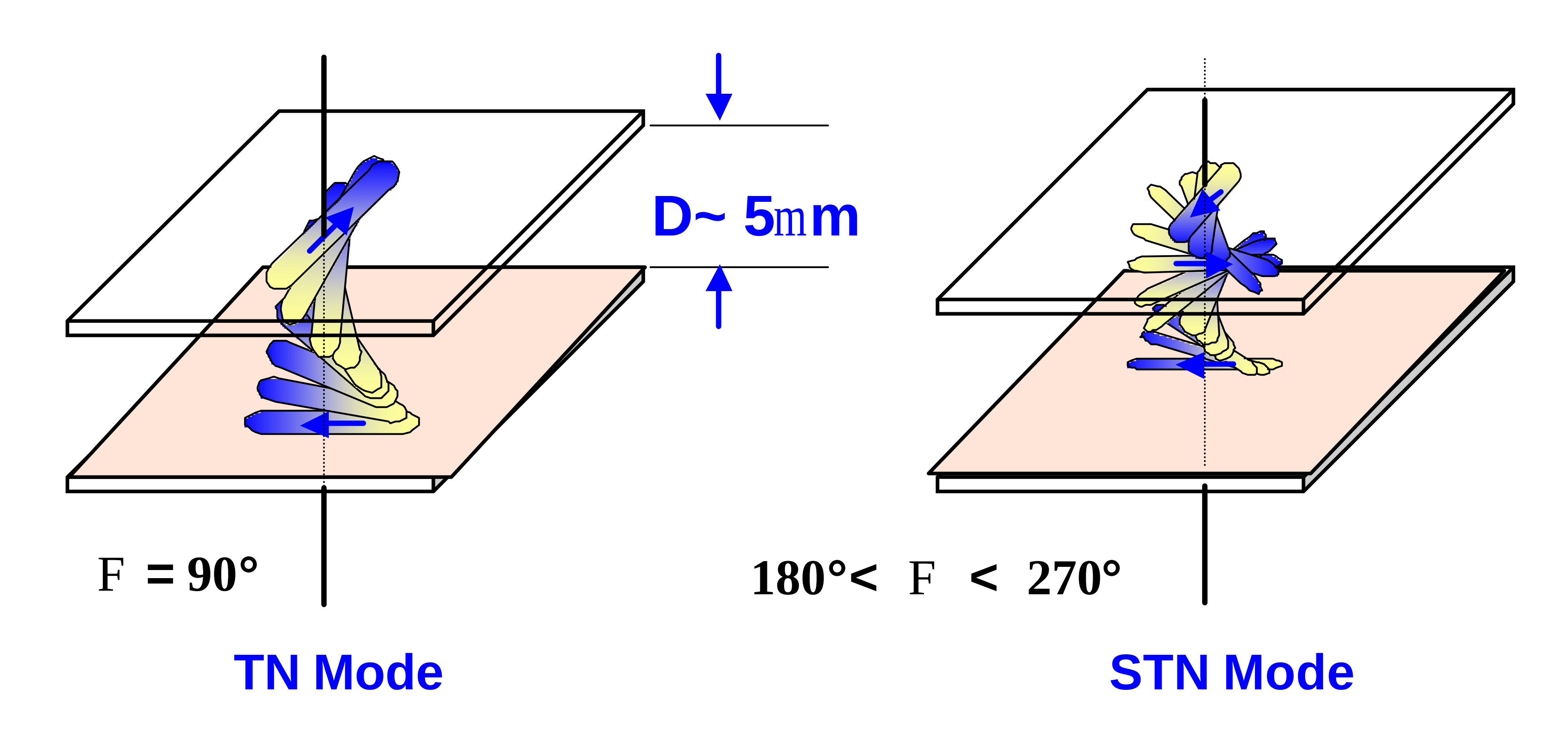


Figure 7. Orientation of L/C molecules in TN and STN cells

Design of TN Cell

Gooch-Tarry's Law: $$T = \left[\sin^2\left(\frac{p}{2}\sqrt{1+u^2}\right)\right] / \left(1+u^2\right)$$

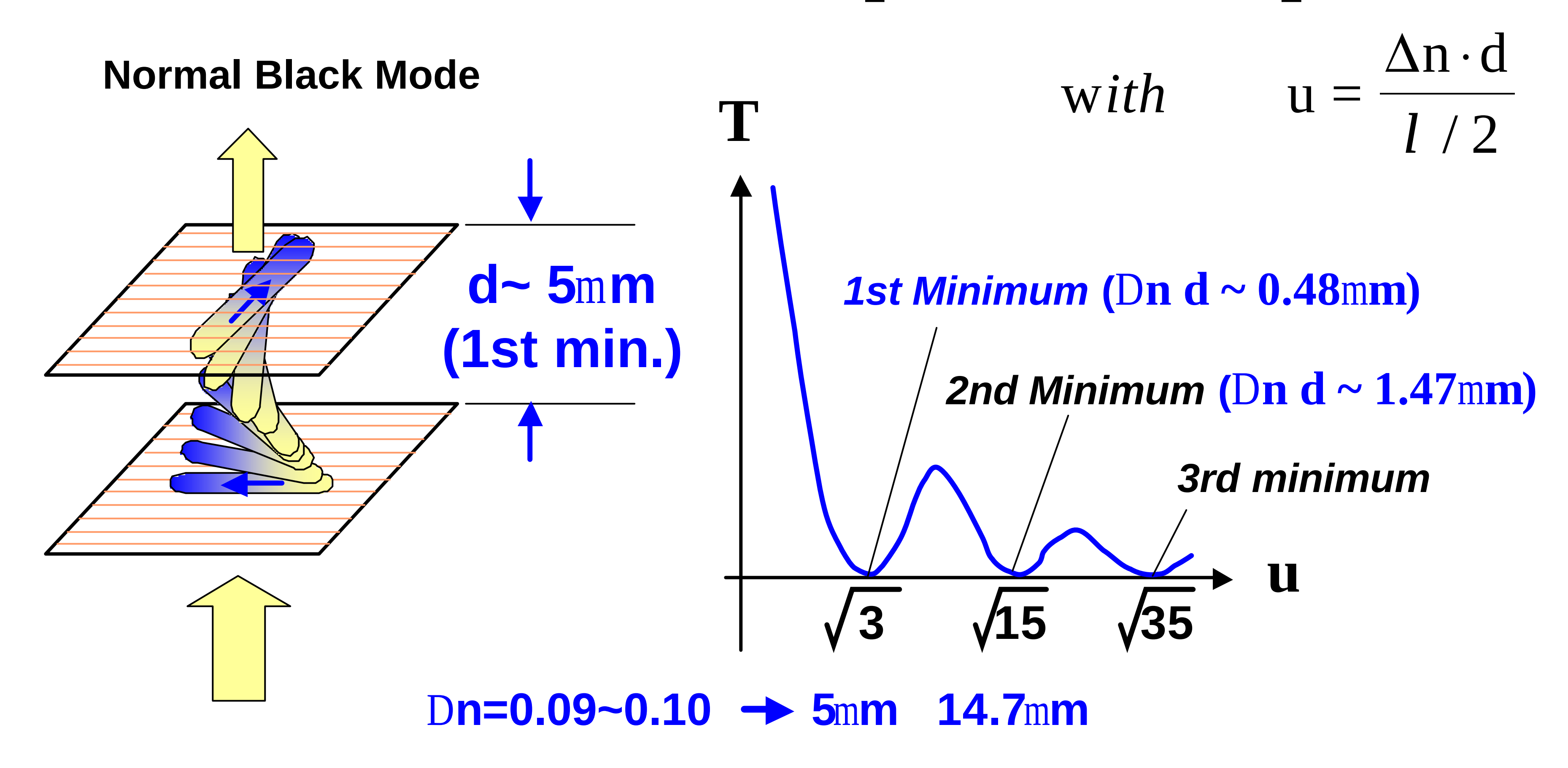
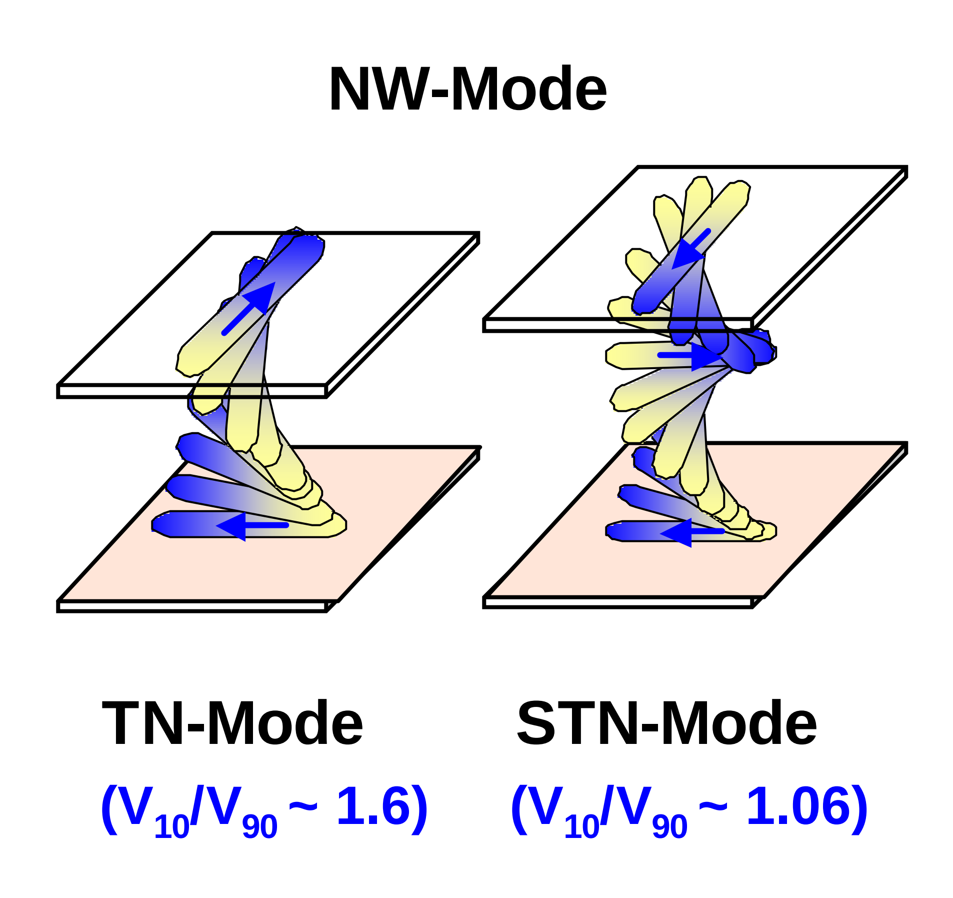


Figure 8. Design of TN cell

V-T Characteristics



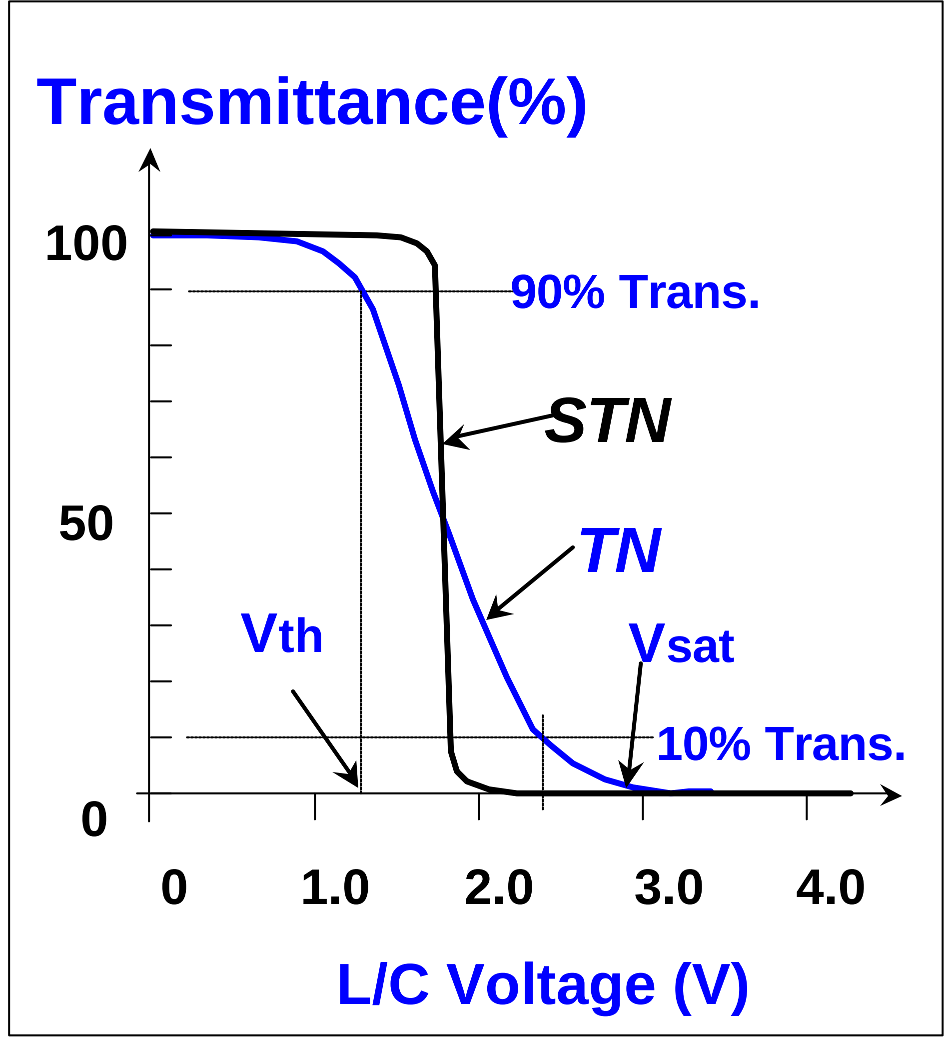


Figure 9. V-T curves for TN and STN cells in NW mode

NW Mode TN Cell

Normal White (NW) Mode:

- **Higher C/R, True Black**
- **Less Cell Gap Dependent**

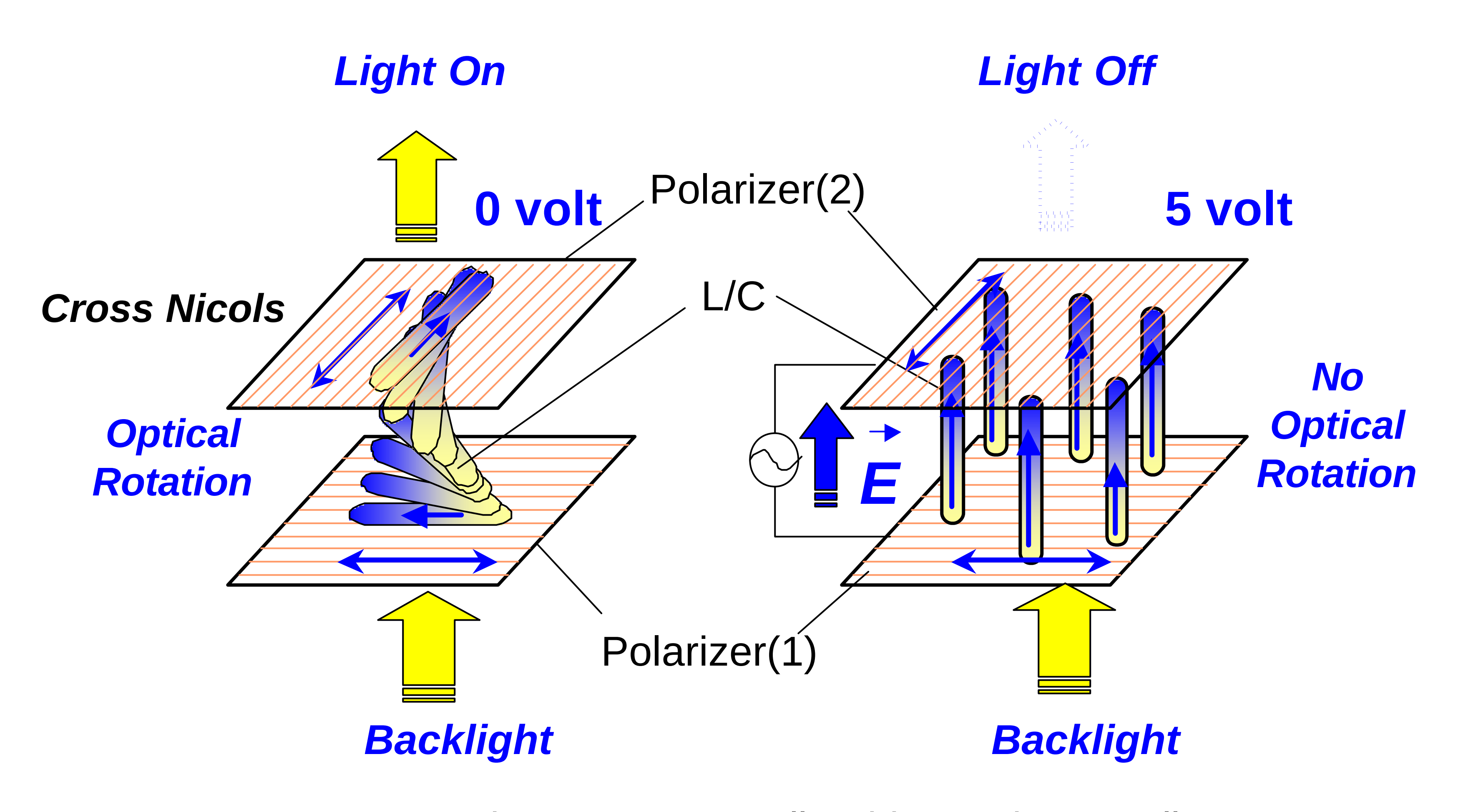


Figure 10. Normally white mode TN cell

NB Mode TN Cell

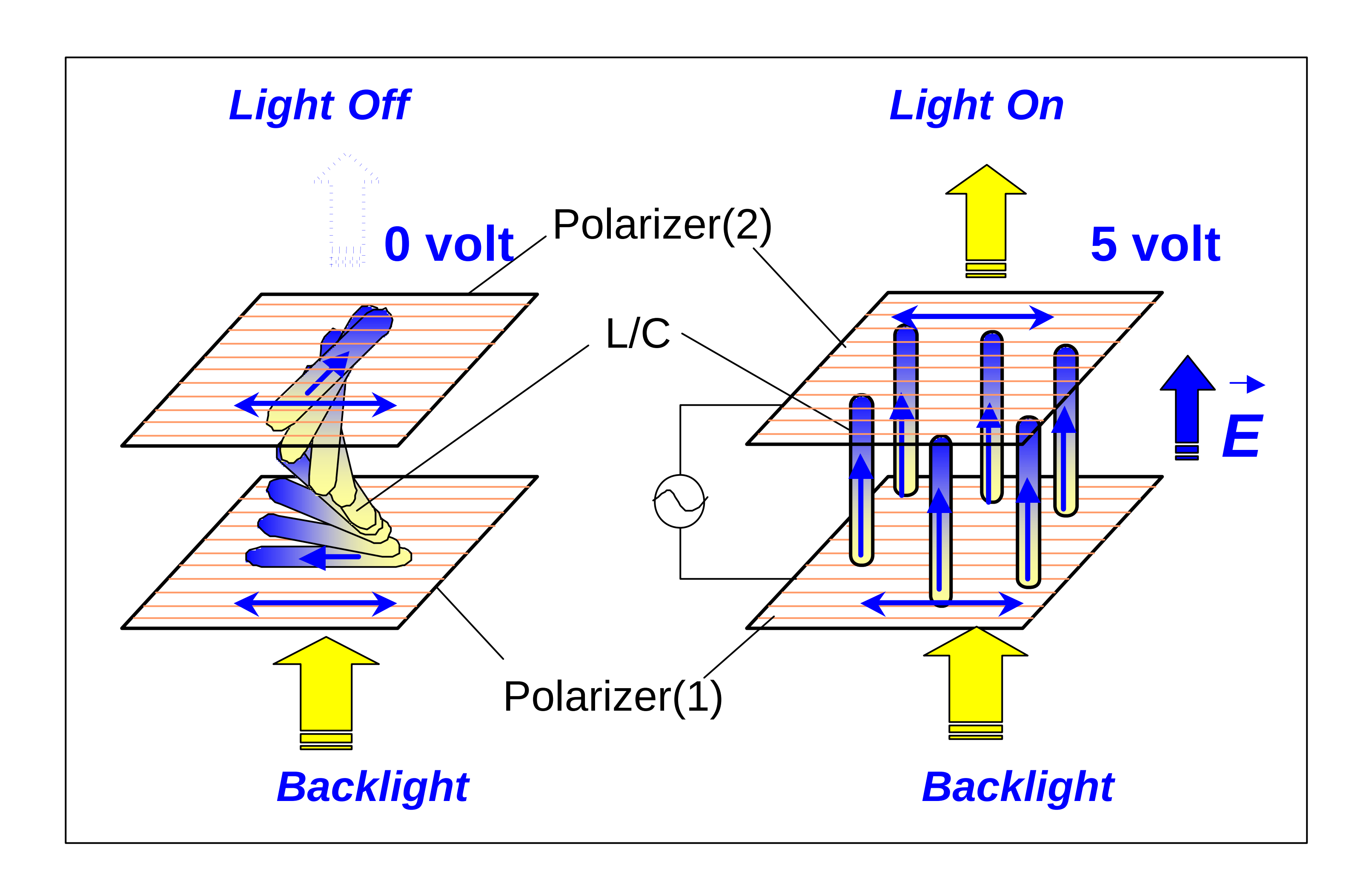


Figure 11. Normally black mode TN cell

II. Liquid Crystal Displays

- Passive and Active Matrix LCD’s
- Kinds of AMLCD’s






Liquid Crystal Operating Modes

- **TN (Twisted Nematic)**
- **STN(Super TN)**
- **DSTN(Double STN)**
- **FLC(Ferroelectric LC)**
- **GH(Guest-Host)**
- **DS(Dynamic Scattering)**
- **PDLC(Polymer Dispersed LC)**
- **VA(Vertical Alignment)**
- **IPS(In-plane Switching)**

Segment & Dot-Matrix Driving

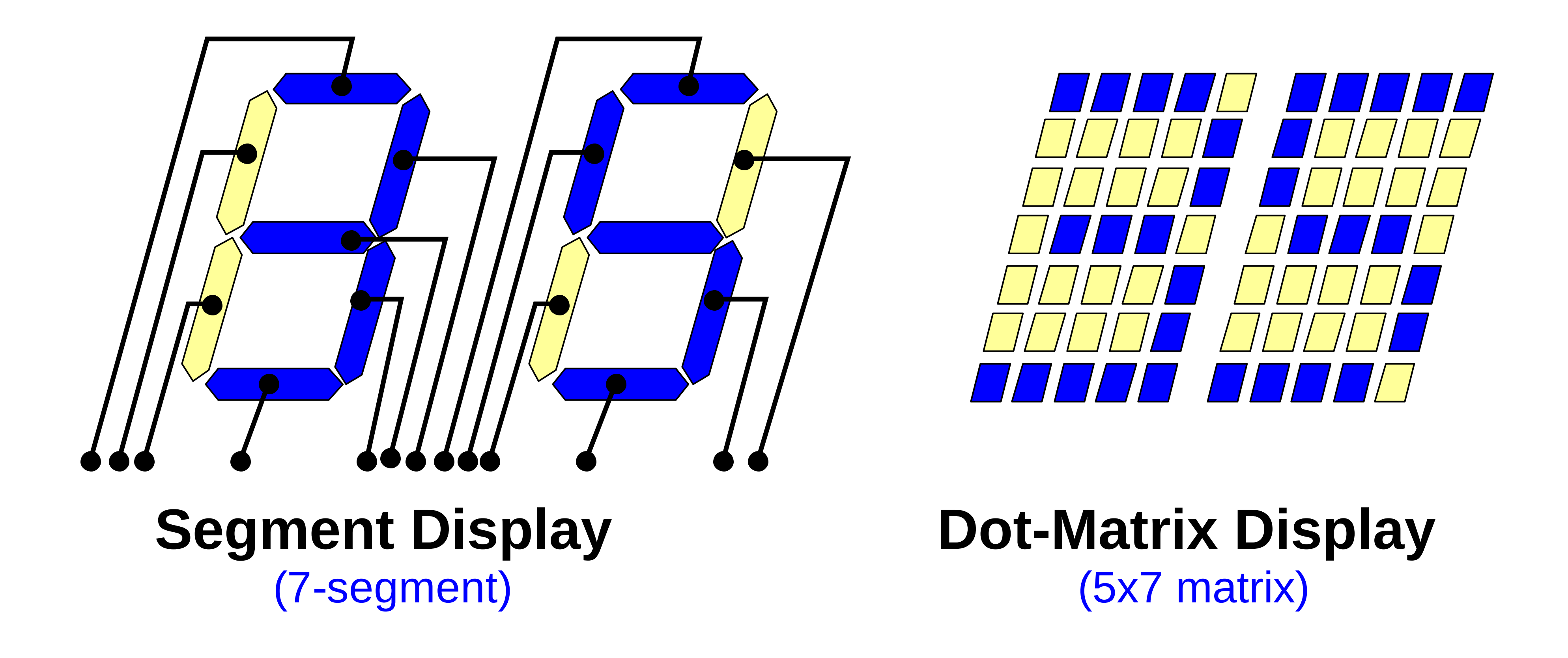


Figure 12. Example of rendering an L/C image using direct driving

Multiplex Driving of Dot-Matrix Display

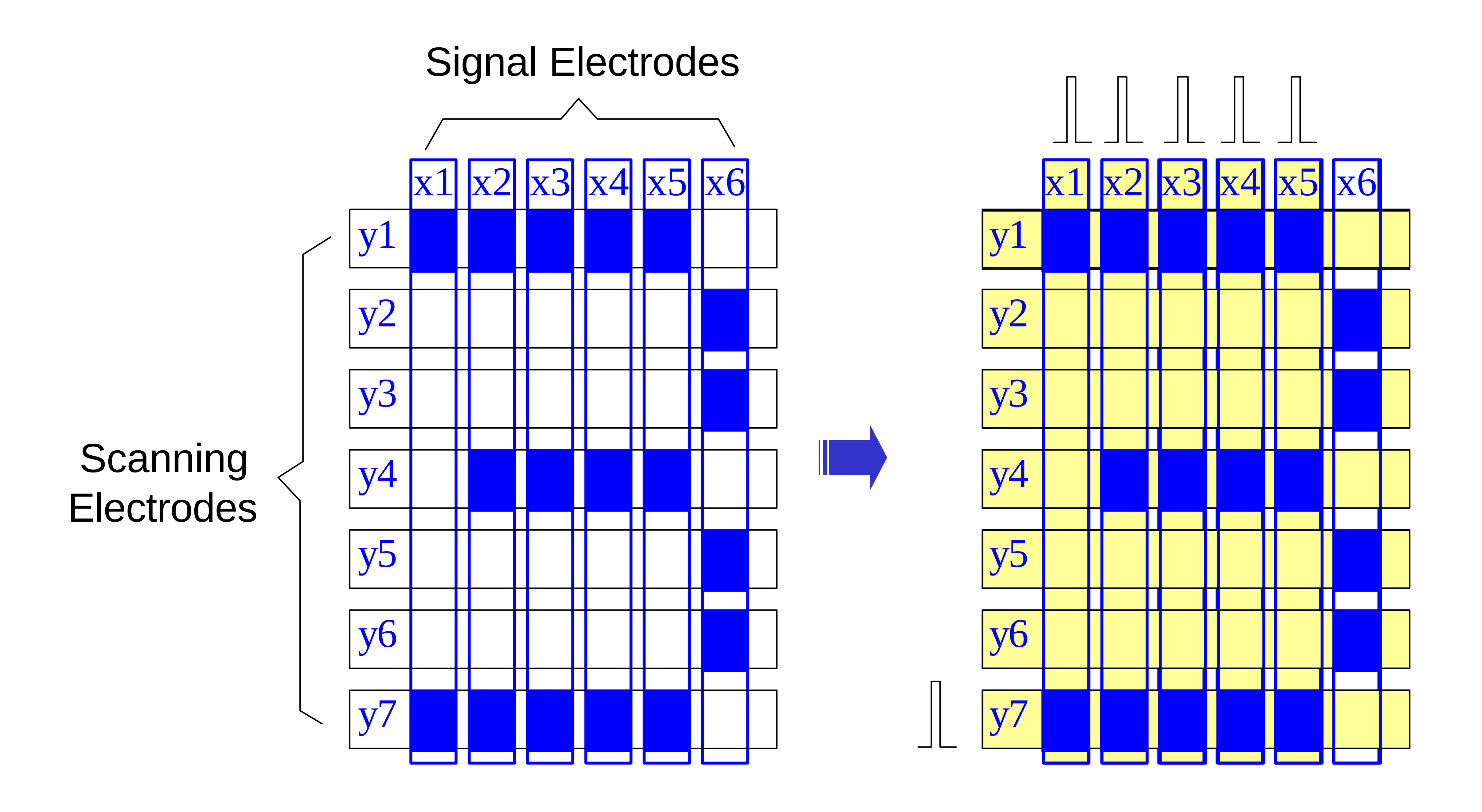


Figure 13. Example of rendering an L/C image by multiplex driving

Application of LCDs

- **Projection Type:** LCD Projector, OHP, Projection TV
- **Direct View Type:** Notebook PC, LCD Monitor, Potable TV, ViewCam
- **Reflective Type:** PDA, Cellular Phone, Game
- **Transflective Type :** PDA, etc.








LCD Projector (3-Panel System)

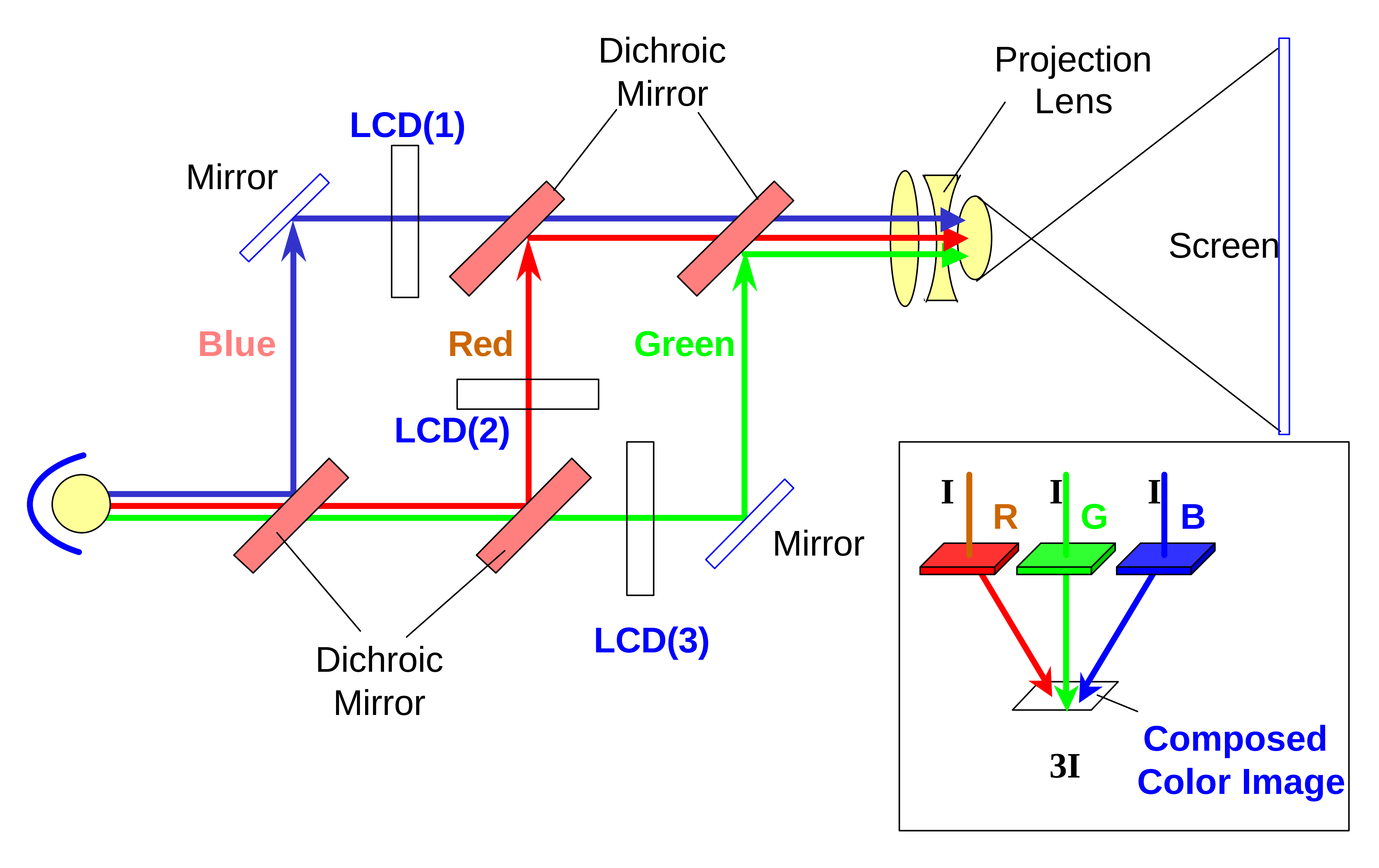


Figure 14. LCD Projector using three black and white LCD’s

LCD Projection TV (Single-Panel System)

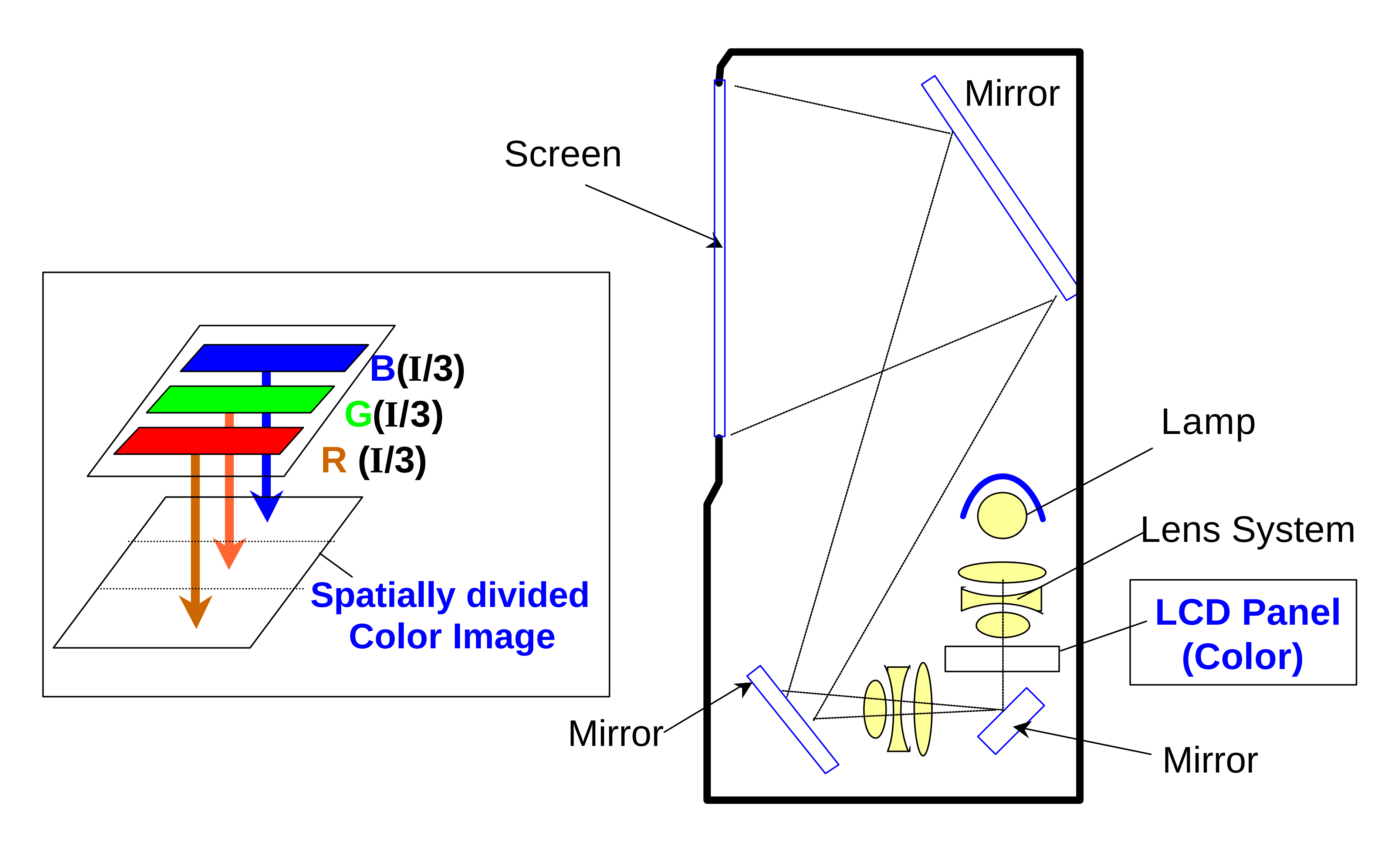


Figure 15. LCD projection TV using a color LCD

Color TFT-LCD Module (Direct View)

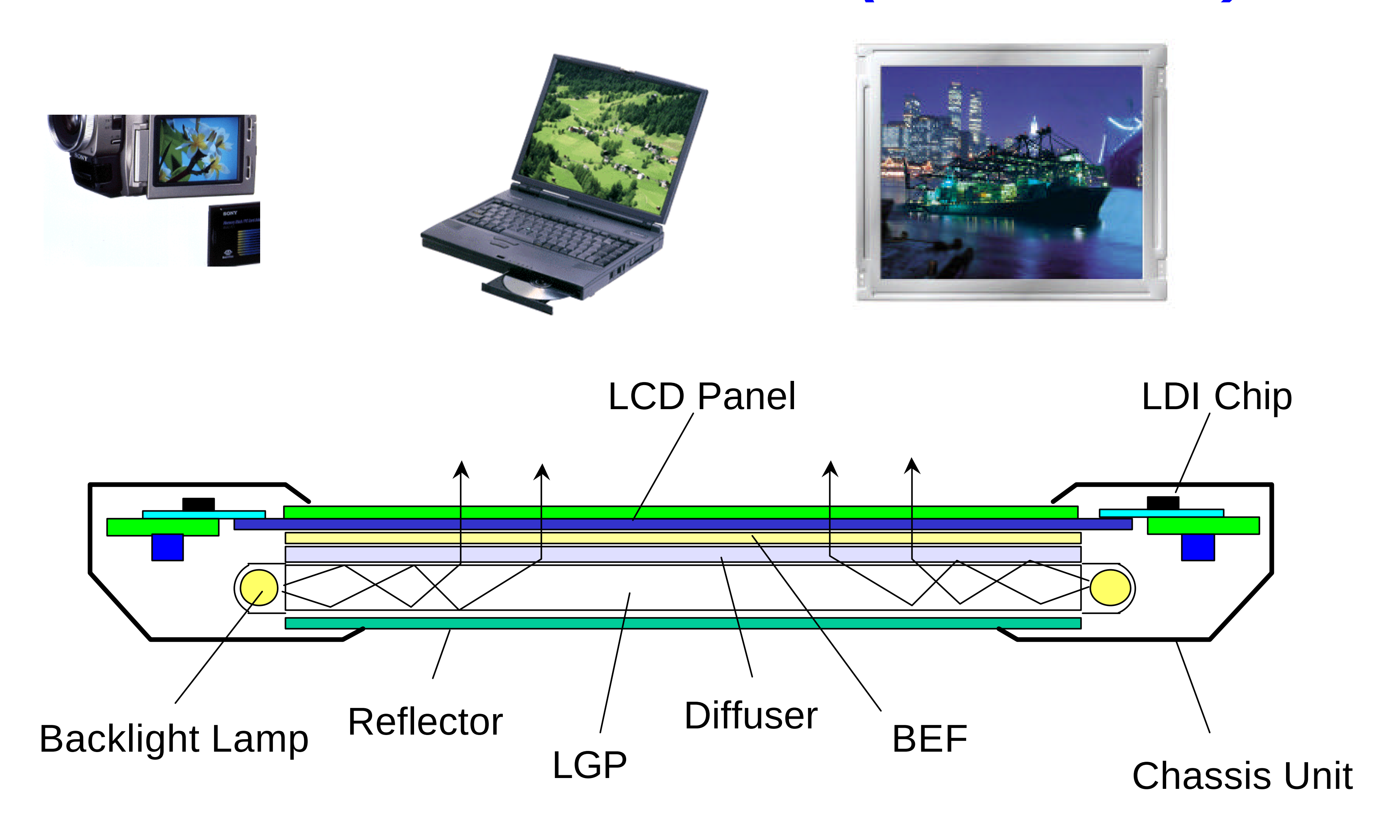


Figure 16. An example of direct view LCD's

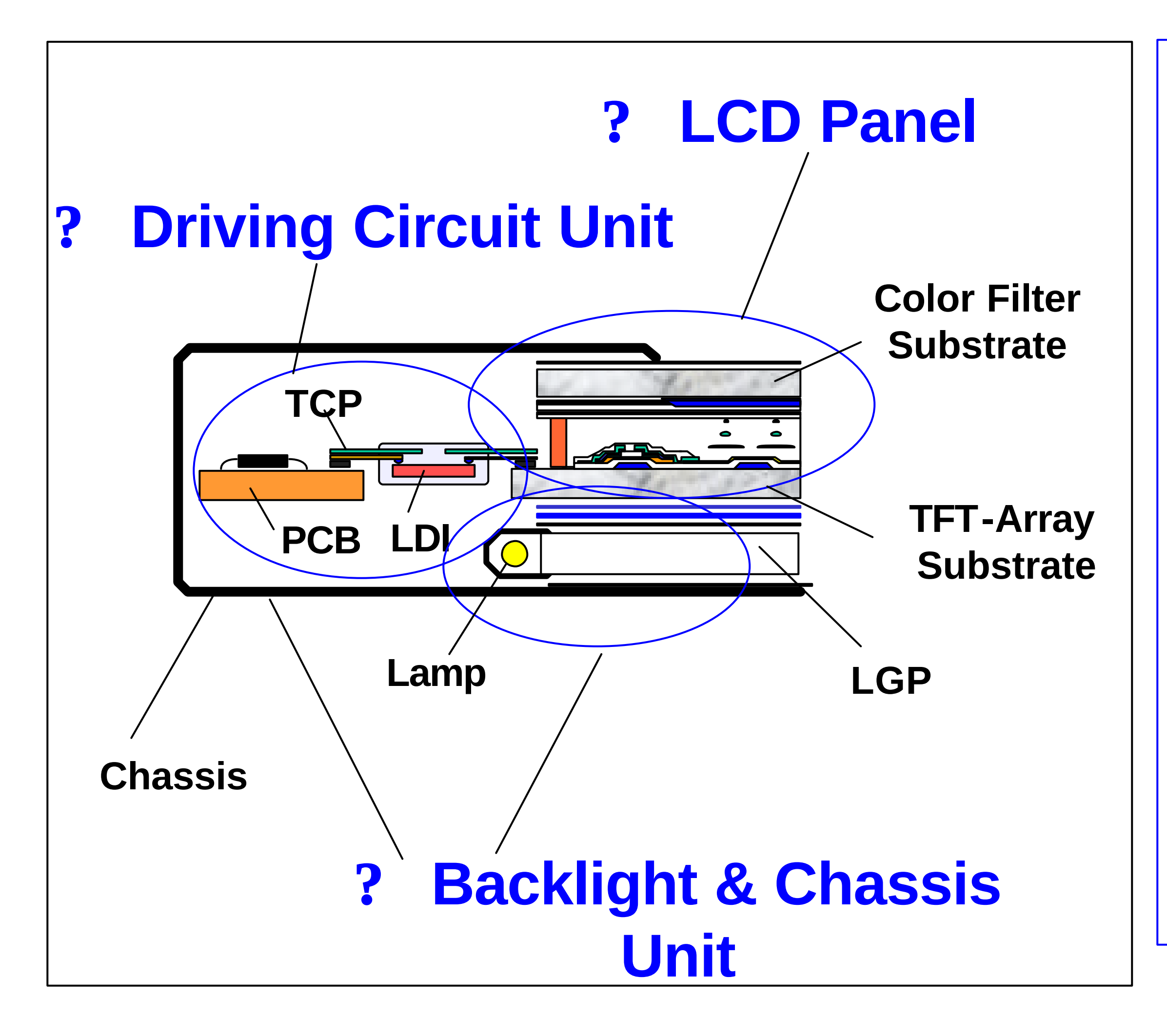
Kinds of AMLCD's

- Passive Matrix LCD (PMLCD)
- Active Matrix LCD (AMLCD)
  - MIM-LCD
  - Diode-LCD
  - TFT-LCD
    - a-Si TFT-LCD
    - poly Si-LCD
      - Low Tem. poly-Si LCD
      - High Tem. poly-Si LCD

III. Structure of Color TFT-LCD

- Color TFT-LCD Panel
- Driving Circuit Unit
- Backlight and Assembly Unit

Structure of Color TFT-LCD



- ? **LCD Panel**
  - ? TFT-Array Substrate
  - ? Color Filter Substrate
- ? **Driving Circuit Unit**
  - ? LCD Driver IC (LDI) Chips
  - ? Multi-layer PCBs
  - ? Driving Circuits
- ? **Backlight & Chassis Unit**
  - ? Backlight Unit
  - ? Chassis Assembly

Figure 17. Structure of a color TFT-LCD module

Structure of Color TFT-Panel

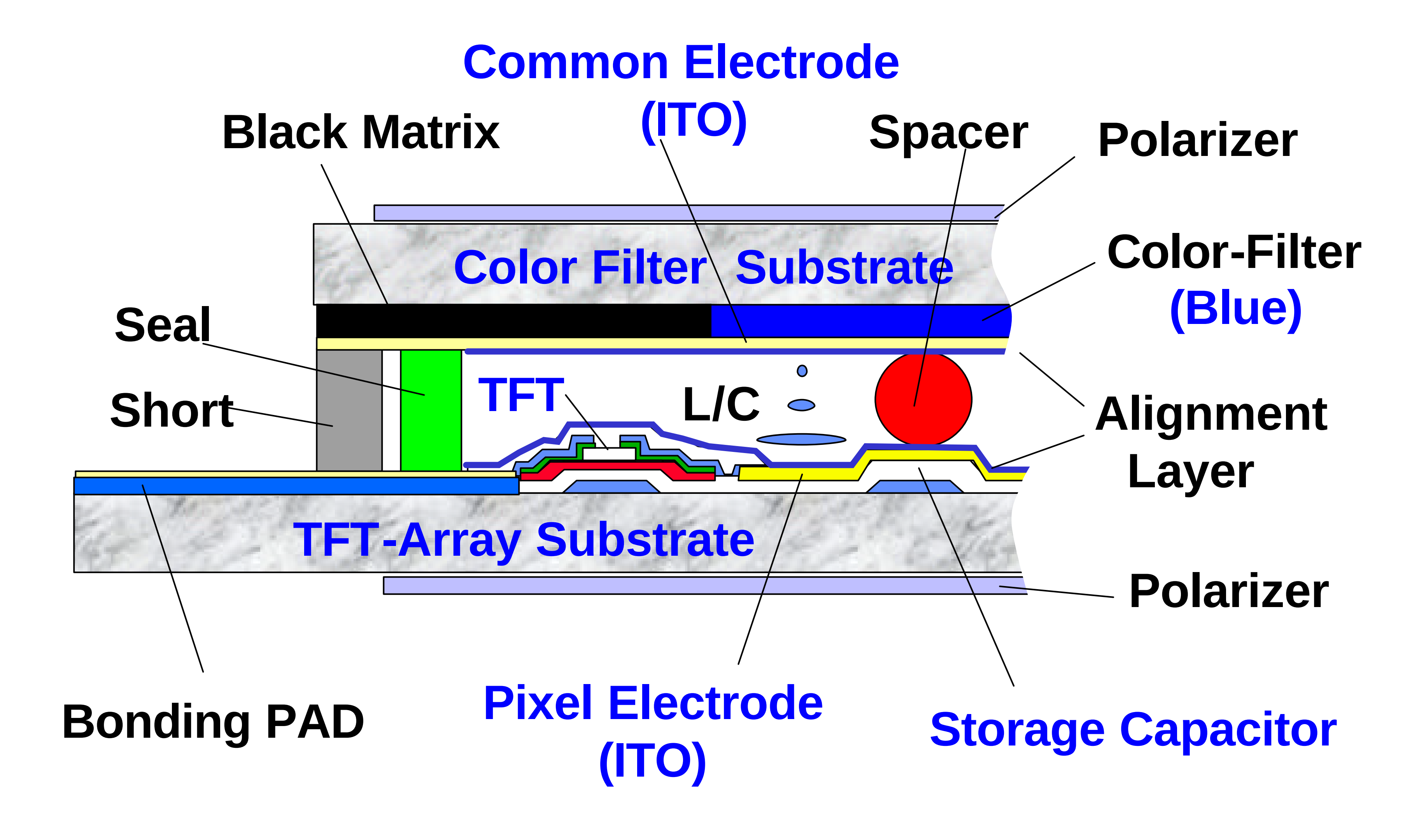


Figure 18. The vertical structure of a color TFT-panel

Structure of Driving Circuit Unit

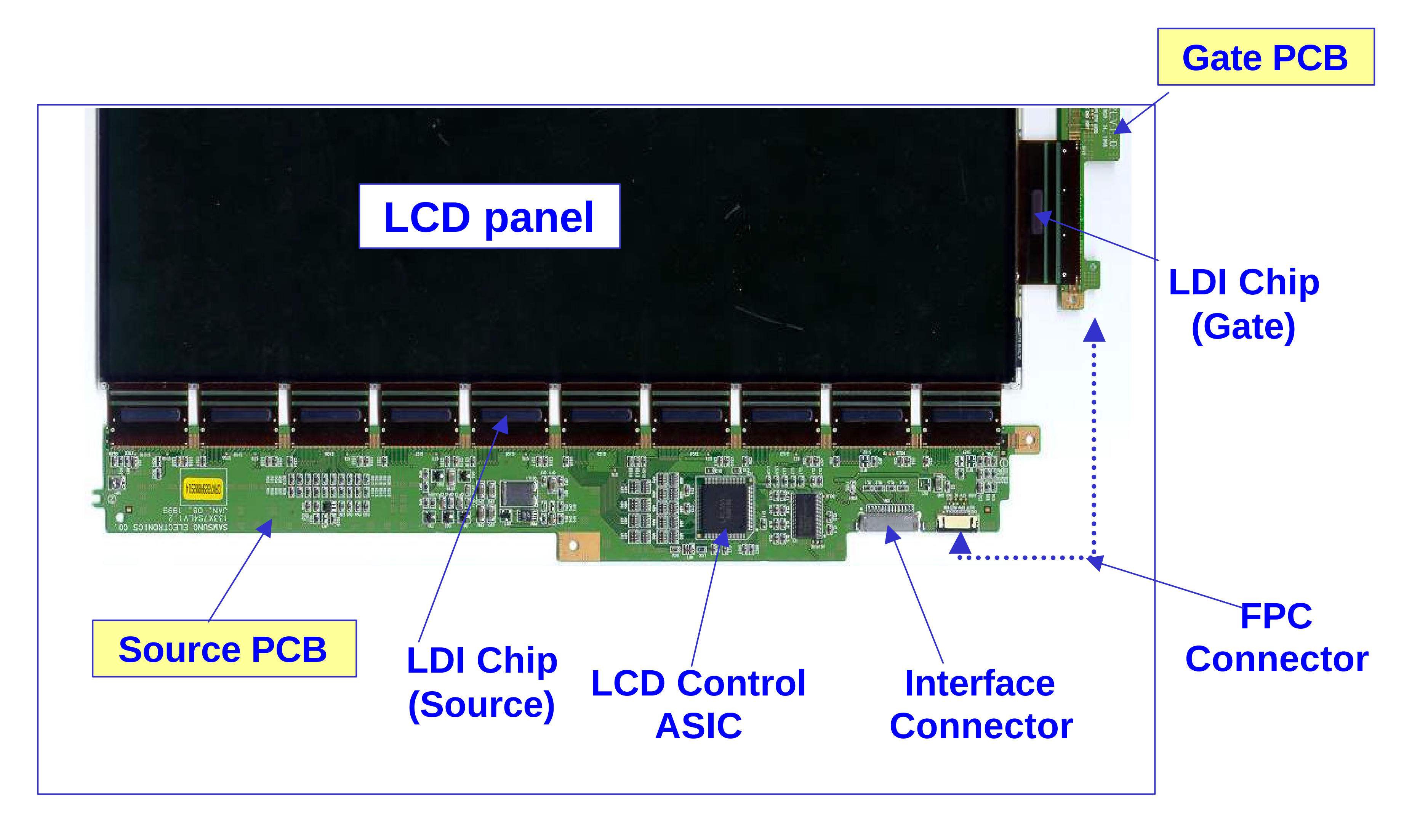
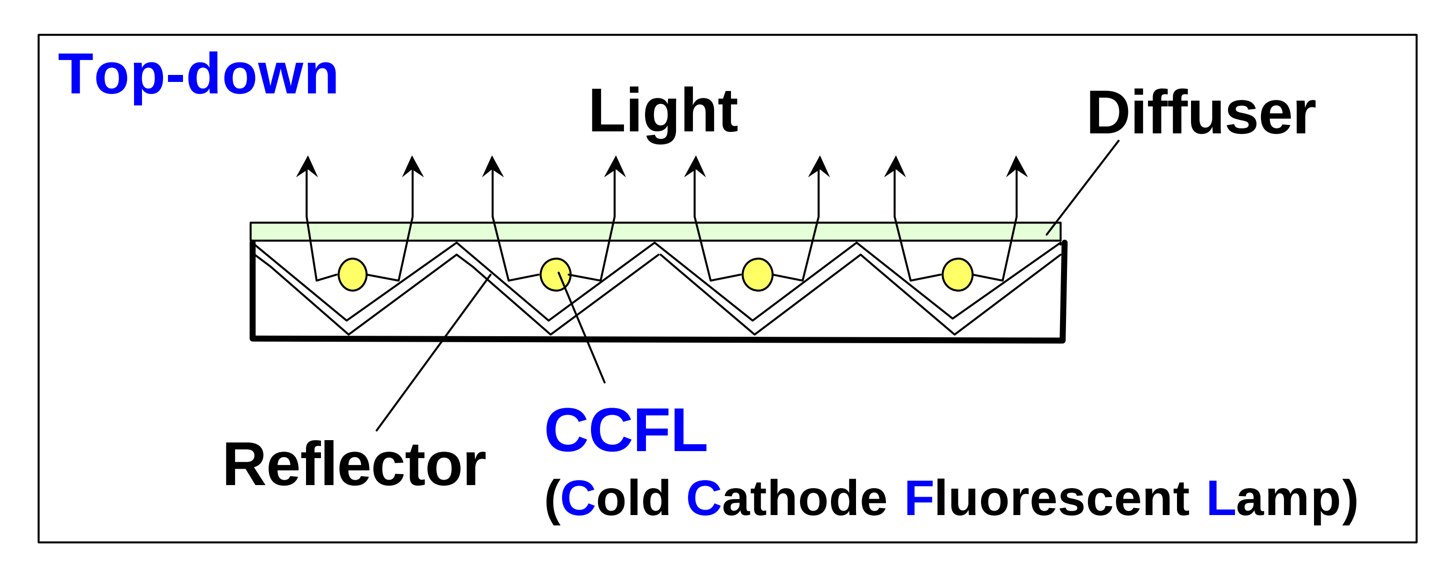


Figure 19. Assembly of LCD driving circuits

Types of Backlight Units



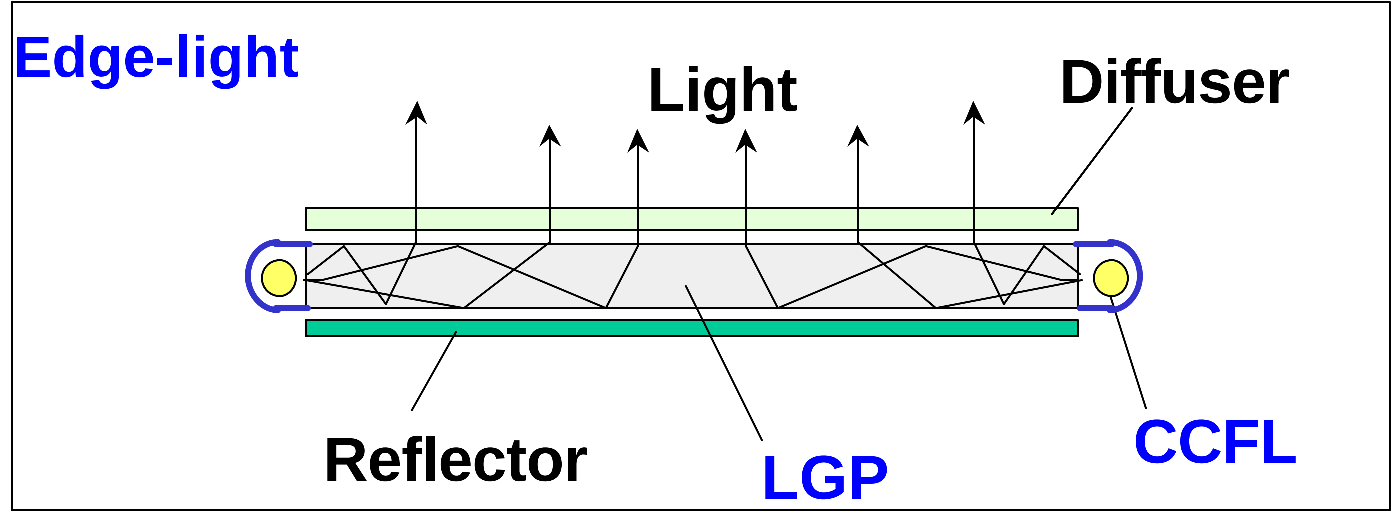


Figure 21. Two different types of LCD backlight systems

Types of LCD Module Package

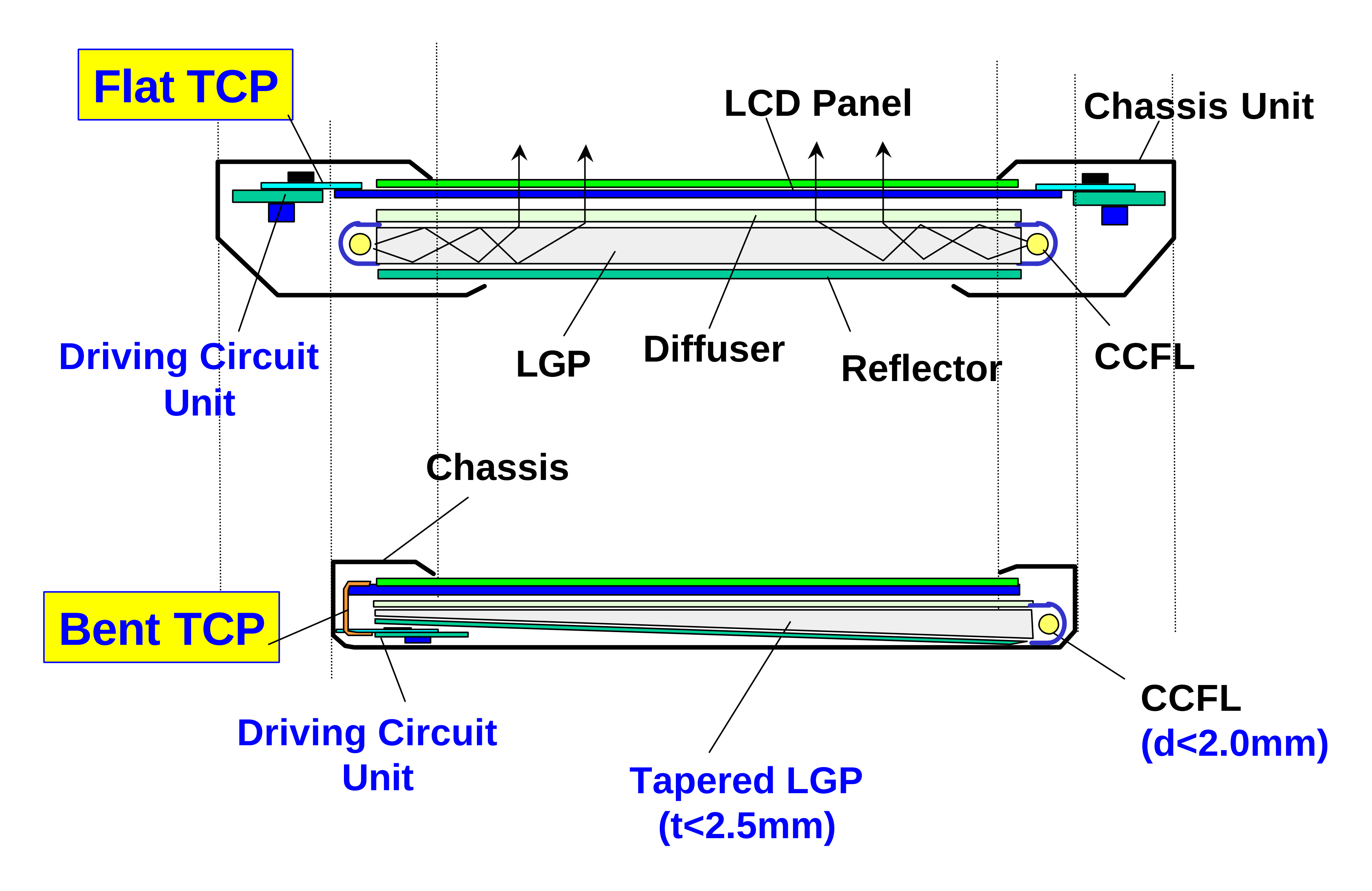


Figure 20. Slim type LCD module package

Improvement of Backlight Brightness

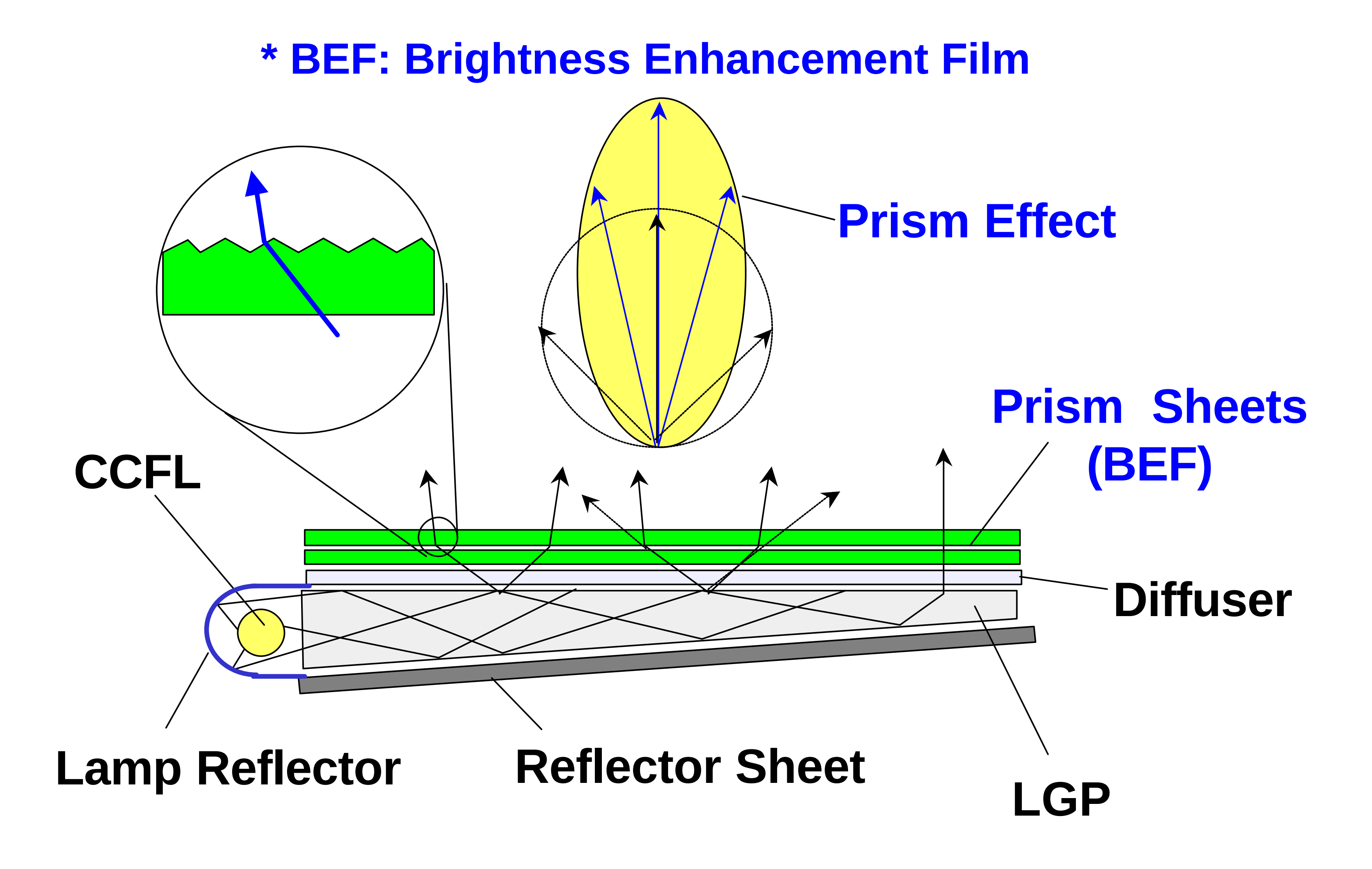


Figure 22. Improvement of B/L brightness using BEF

IV. Basic Operation Principles and Design of Color TFT-LCD

- Operation of TFT-LCD Pixels
- Gray Scale Generation
- Color Generation

-- Break

- TFT Design
- Storage Capacitor Design
- Signal Bus-Line Design
- Aperture Ratio
- Design for Redundant

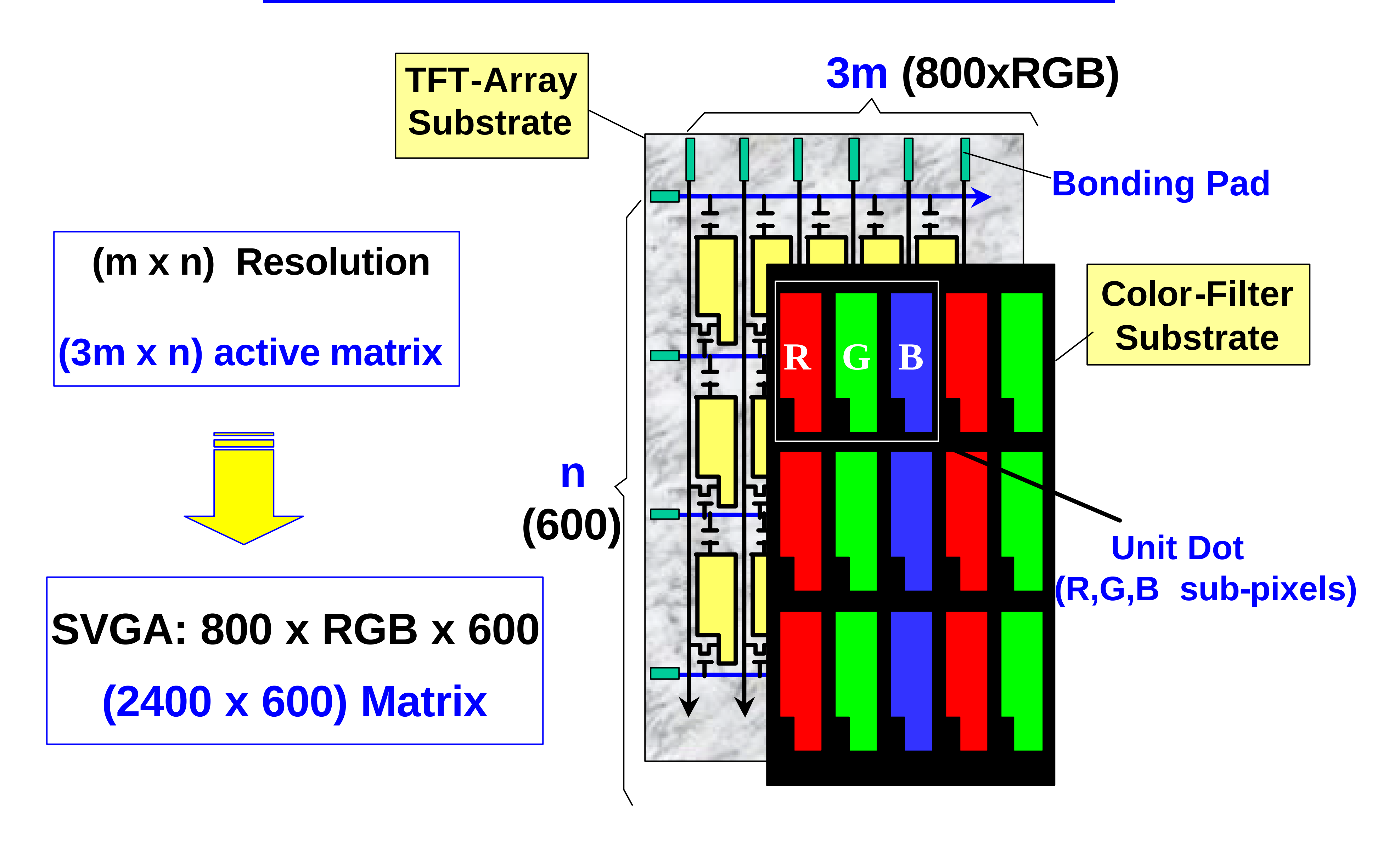


Figure 23. Active matrix structure of a color TFT-panel

Resolution of Color LCDs

	Resolution	# of Dot	# of Pixel	Aspect Ratio	Remark
	320 x 240	76,800	230,400	4:3	Quarter VGA
	640 x 400	256,000	768,000	16:10	EGA
★	640 x 480	307,200	921,600	4:3	VGA
	800 x 480	384,000	1,152,000	15:9	Wide VGA
	800 x 600	480,000	1,440,000	4:3	SVGA
	1024 x 600	614,400	1,843,200	~17:10	Wide SVGA
	1024 x 768	786,432	2,359,296	4:3	XGA
	1280 x 1024	1,310,720	3,923,160	5:4	SXGA
	1400 x 1050	1,470,000	4,410,000	4:3	SXGA+
★	1600 x 1200	1,920,000	5,760,000	4:3	UXGA
	1920 x 1200	2,304,000	6,912,000	16:10	Wide UXGA
	2048 x 1536	3,145,728	9,437,184	4:3	★ QXGA
	2560 x 2048	5,242,880	15,728,640	4:3	QSXGA
	3200 x 2400	7,680,000	23,040,000	4:3	QUXGA

Figure 24. Resolution of color LCDs

TFT-Array & Unit Pixel

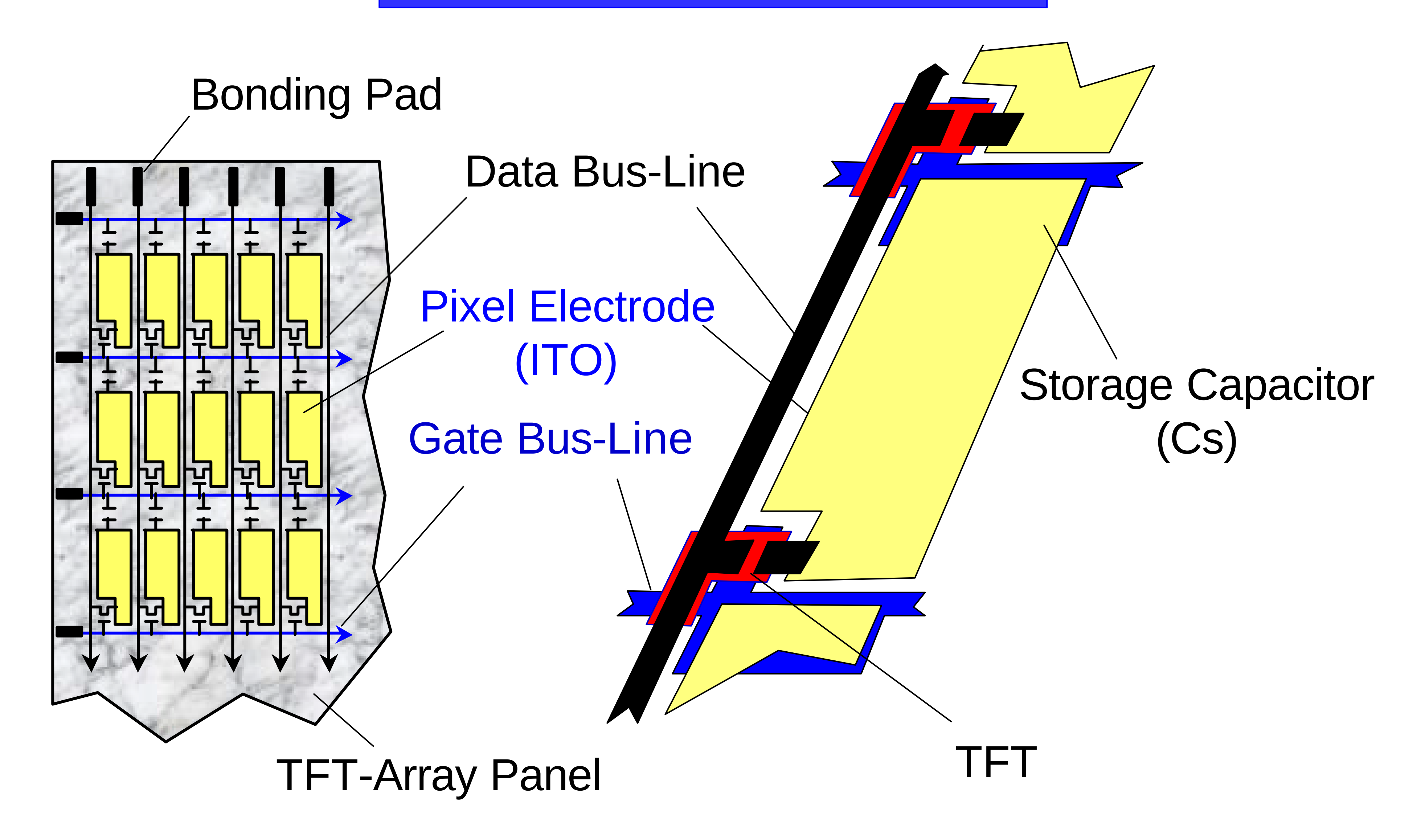


Figure 25. TFT-Array and its unit pixel

Unit Pixel & Equivalent Circuit

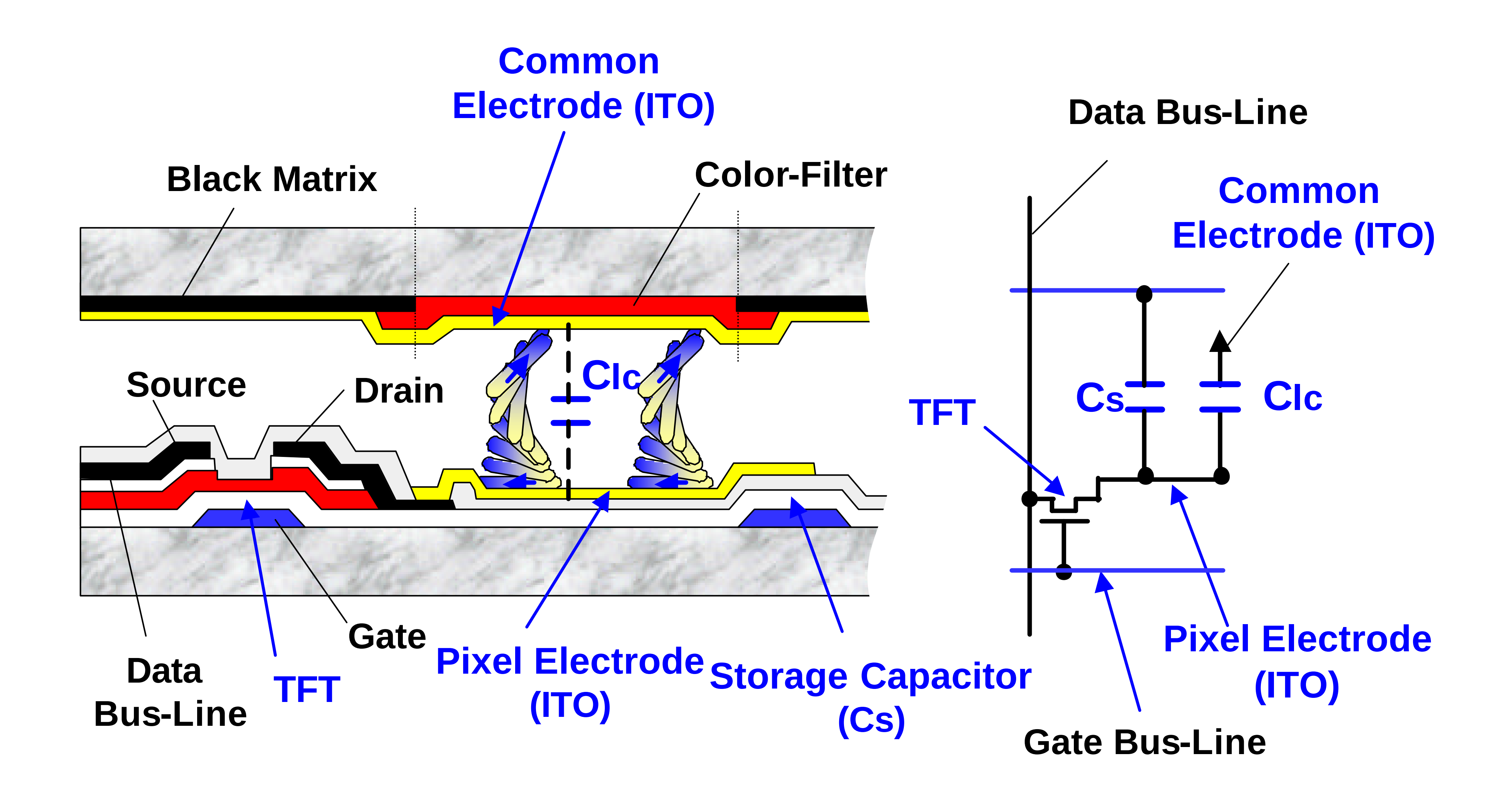


Figure 26. Vertical structure of a pixel and its equivalent circuit

AC Driving of TN-Mode

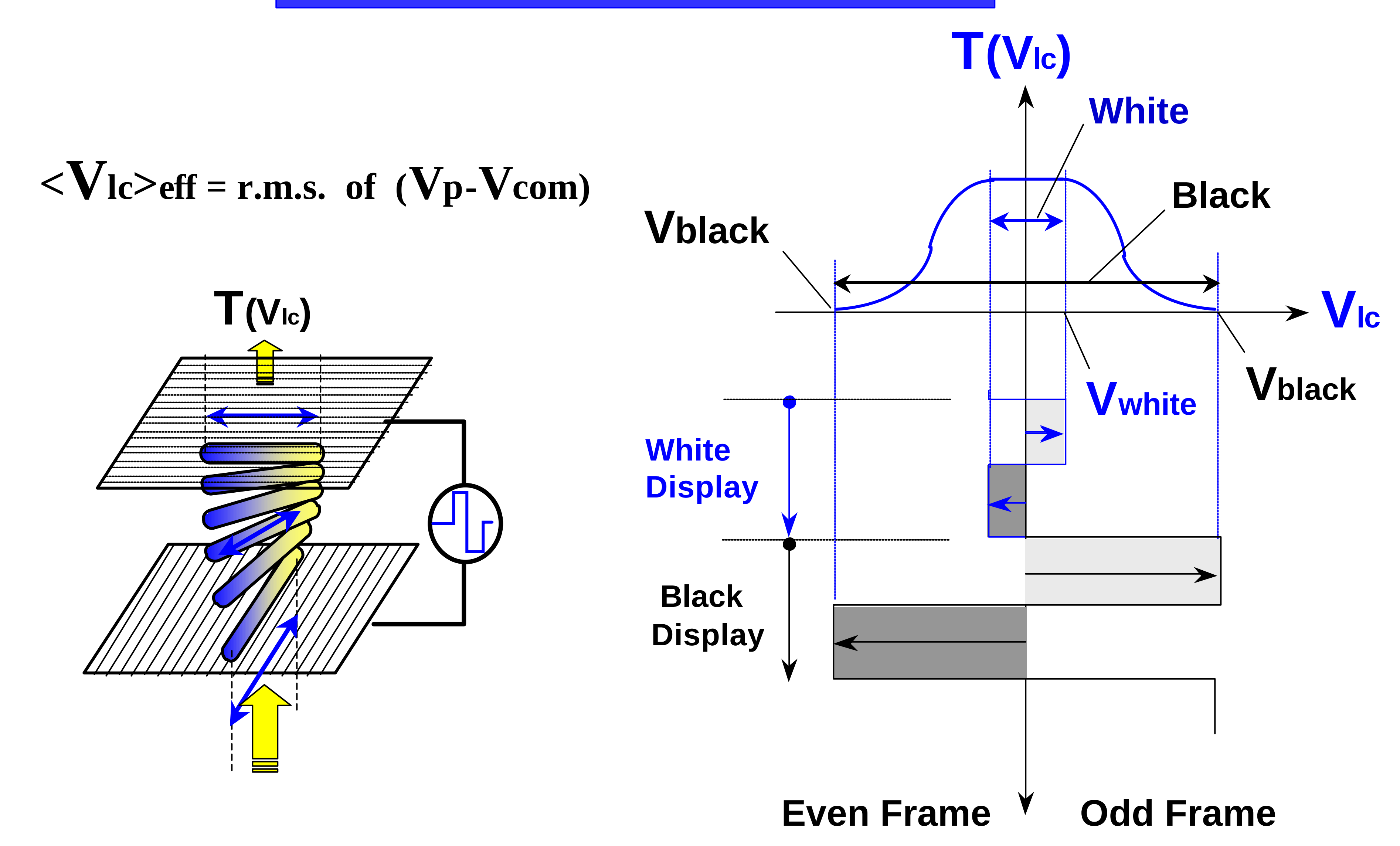


Figure 27. AC driving of a TN-mode L/C

Operation of Unit Pixel

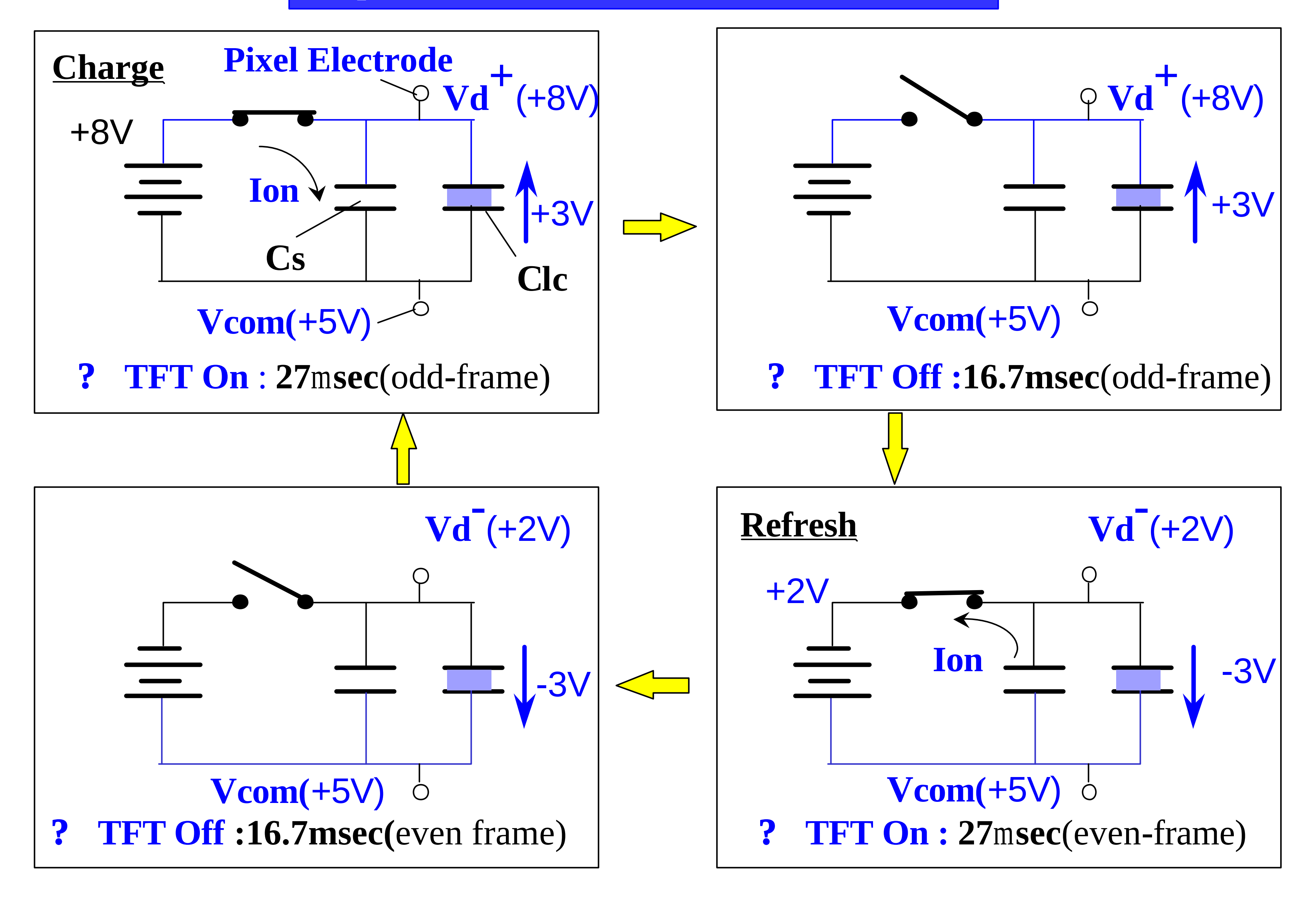


Figure 28. Modeling of a unit pixel operation

Active Addressing of (3x3) Matrix

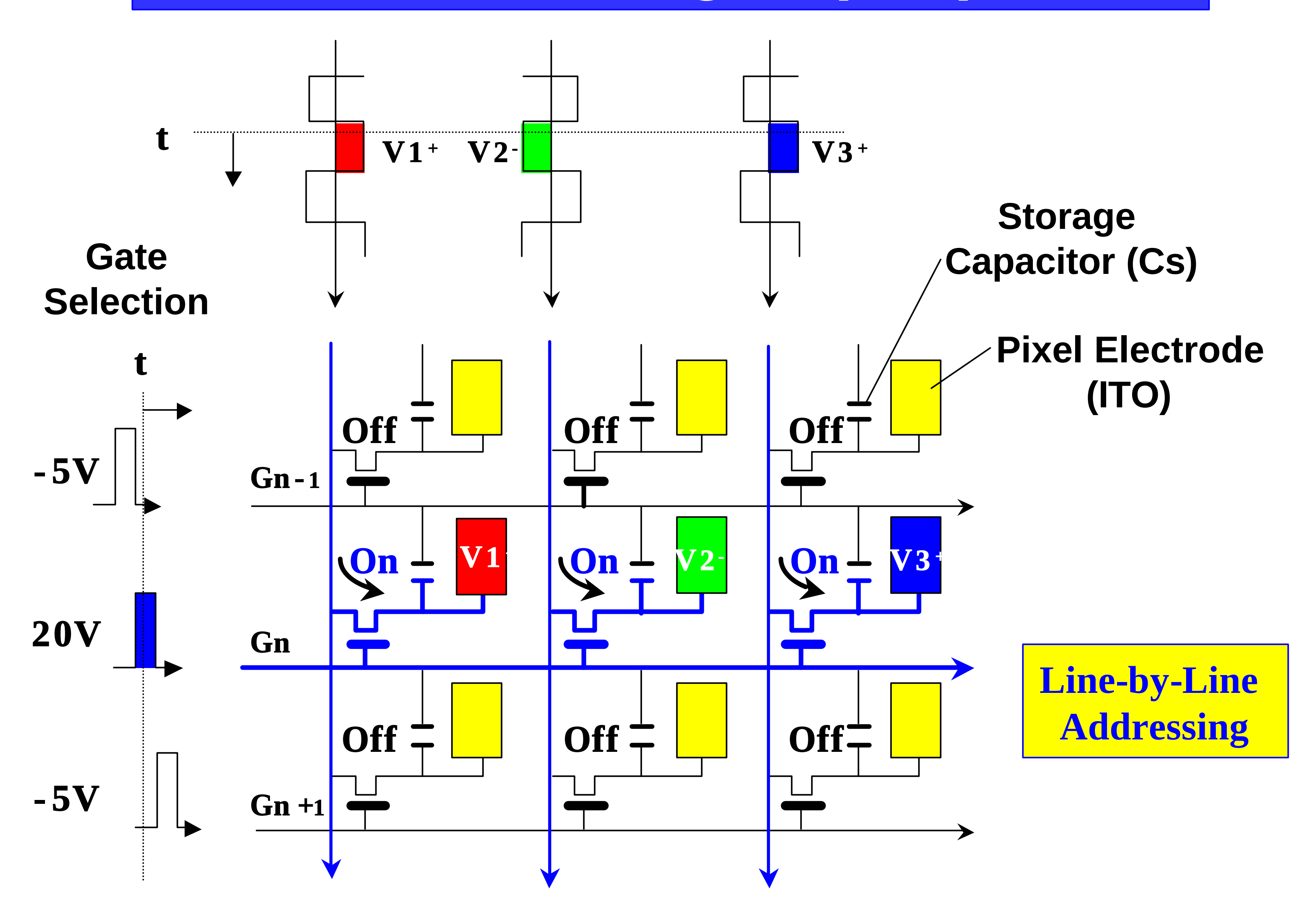
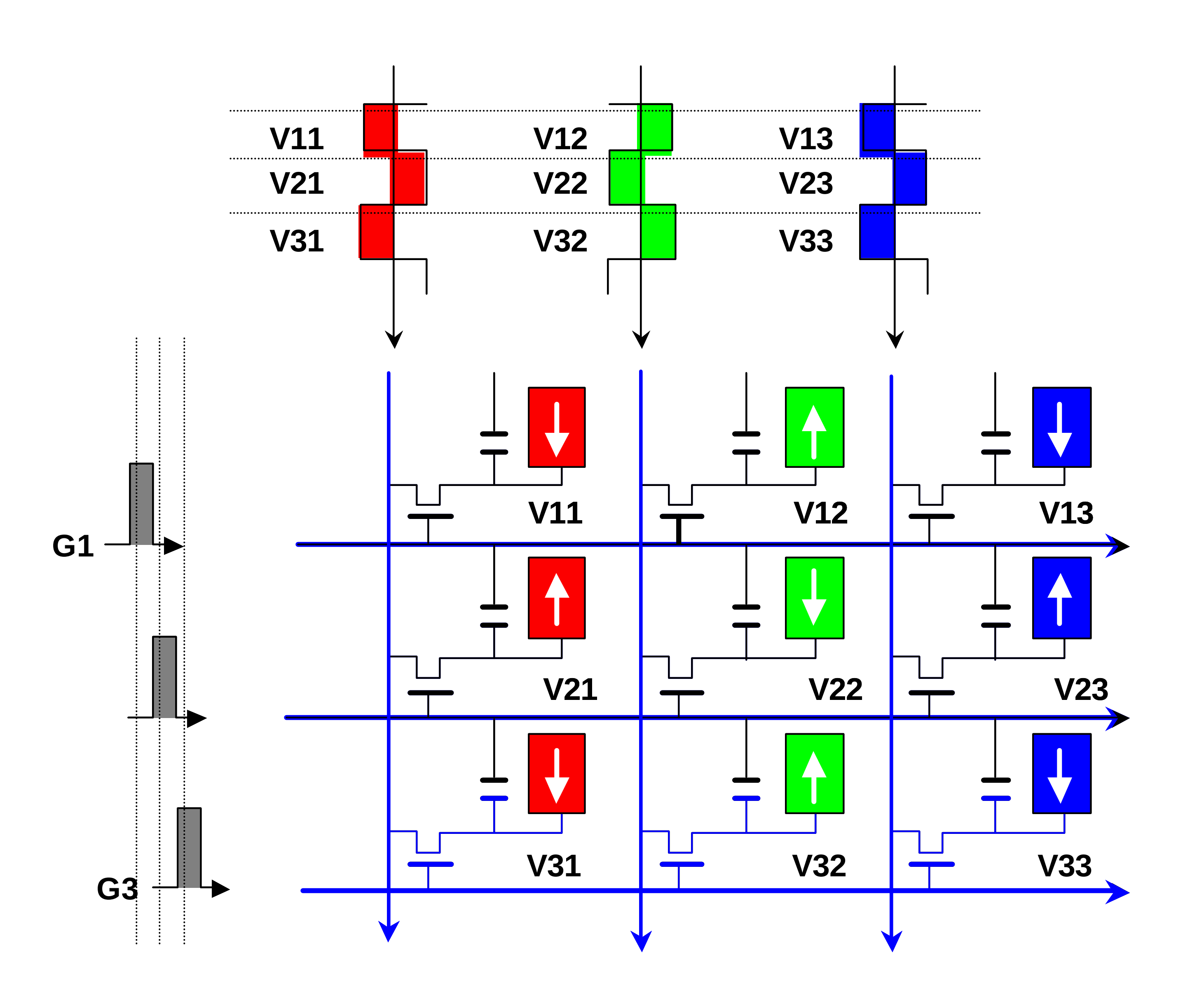


Figure 29. An example of a (3x3) matrix pixel

Animation of a (3x3) Matrix

Odd Frame



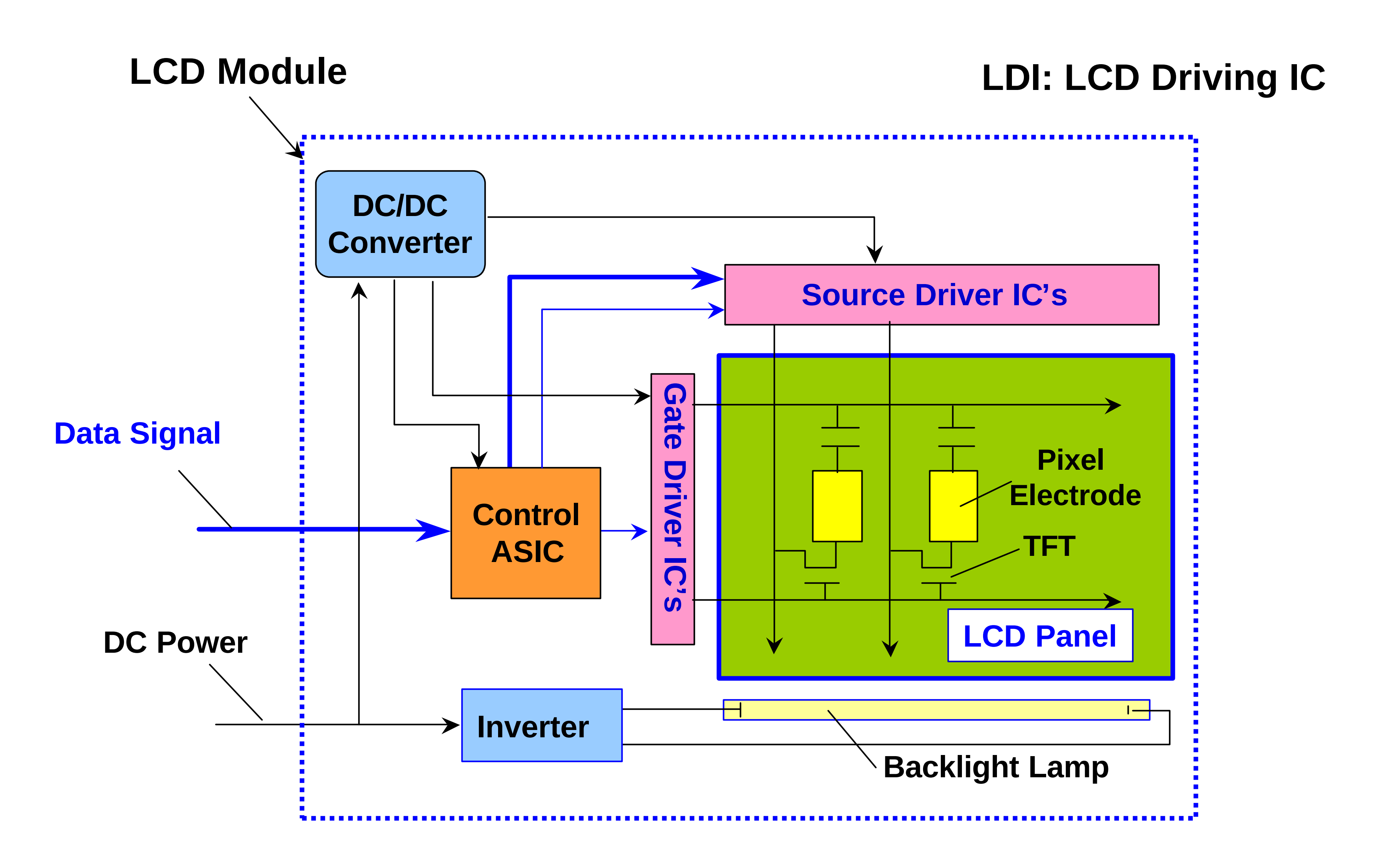


Figure 30. Driving of an LCD panel

Representation of Image on LCD

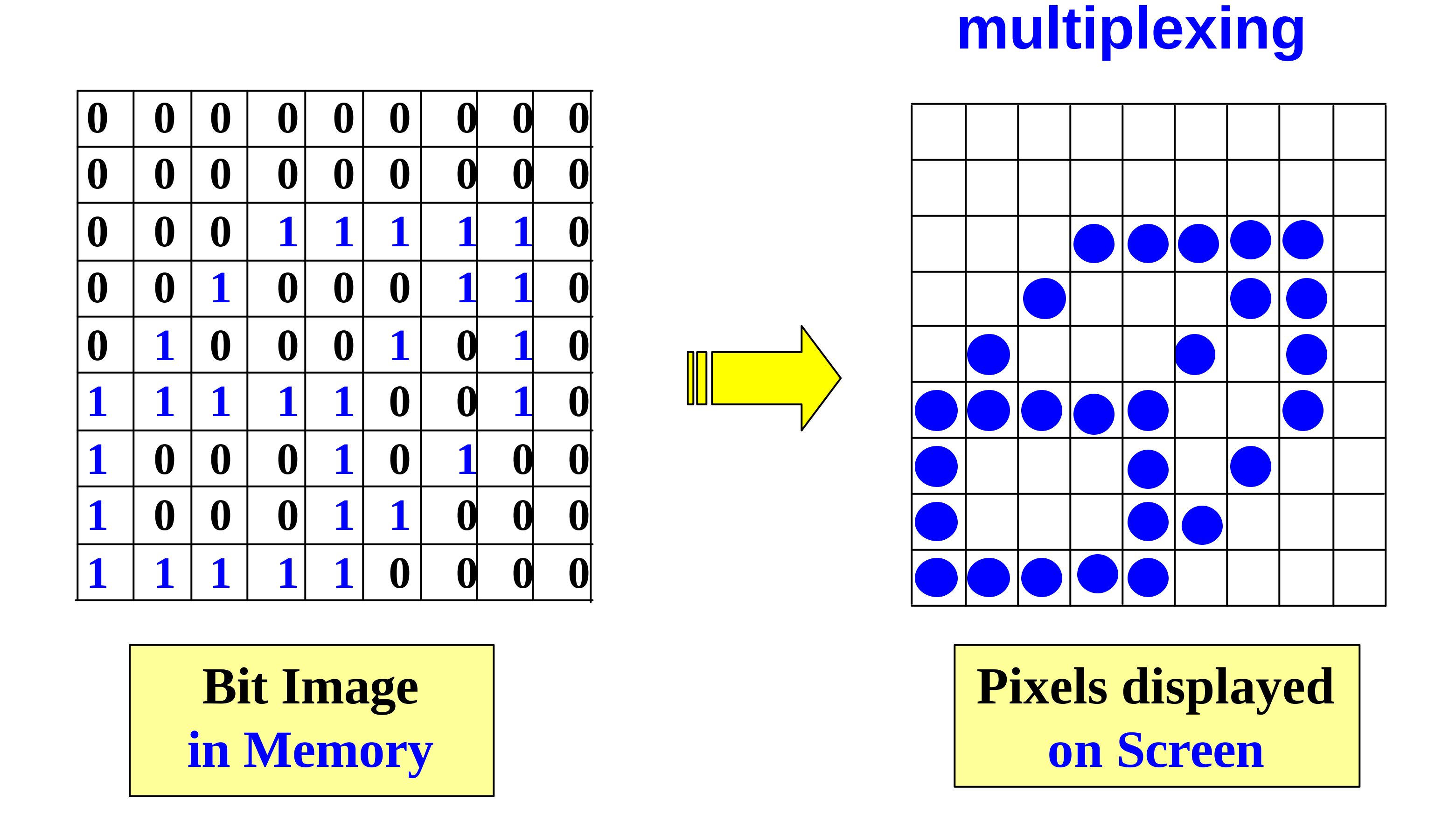


Figure 31. Representation of an image on an LCD

Parasitic Capacitance of TFT

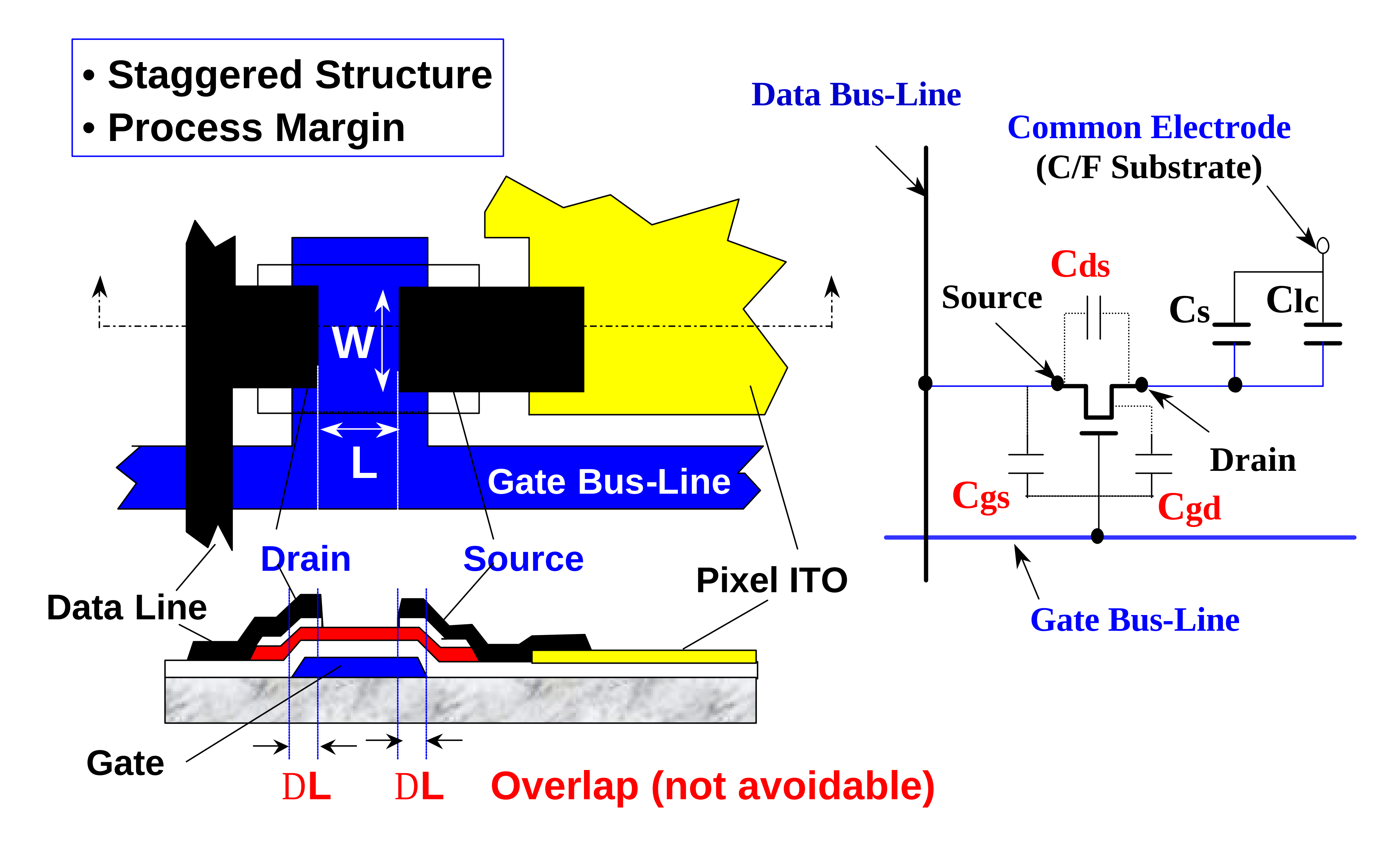


Figure 32. Parasitic capacitors of a TFT

Wave Forms of Pixel Driving Voltages

Kickback Voltage ⇒ $DV = \dfrac{C_{gd}}{(C_{lc} + C_s + C_{gd})} \times V_{p\text{-}p}$

$$\langle V_{lc} \rangle_{eff} = \frac{1}{2\,T_f} \sqrt{\int_{t=0}^{2T_f} \{ V_p(t) - V_{com} \}^2 \, dt}$$

$$V_{offset} = \frac{V_d^+ + V_d^-}{2} - V_{com}$$

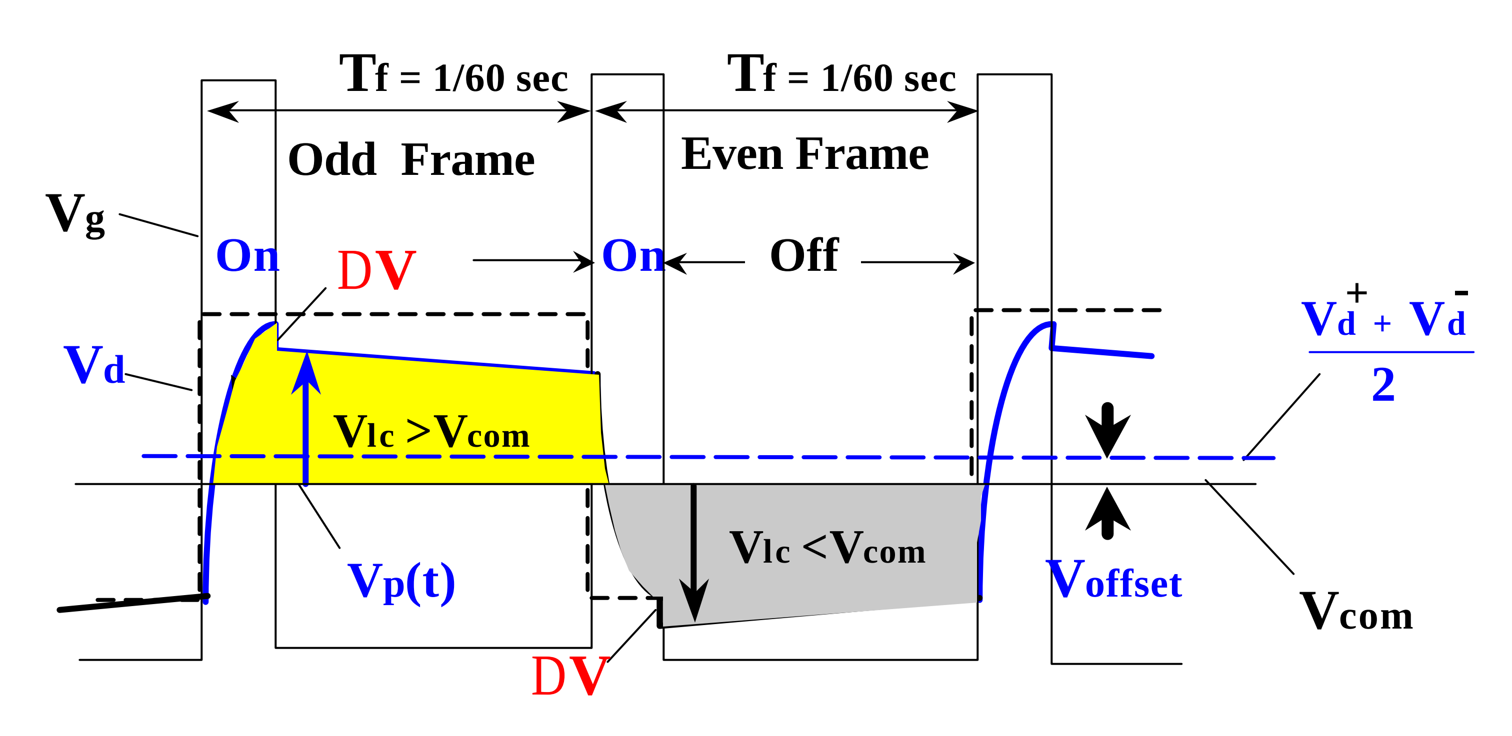


Figure 33. Driving a pixel and the effect of the parasitic capacitance

Polarity Inversion Driving & Flickering

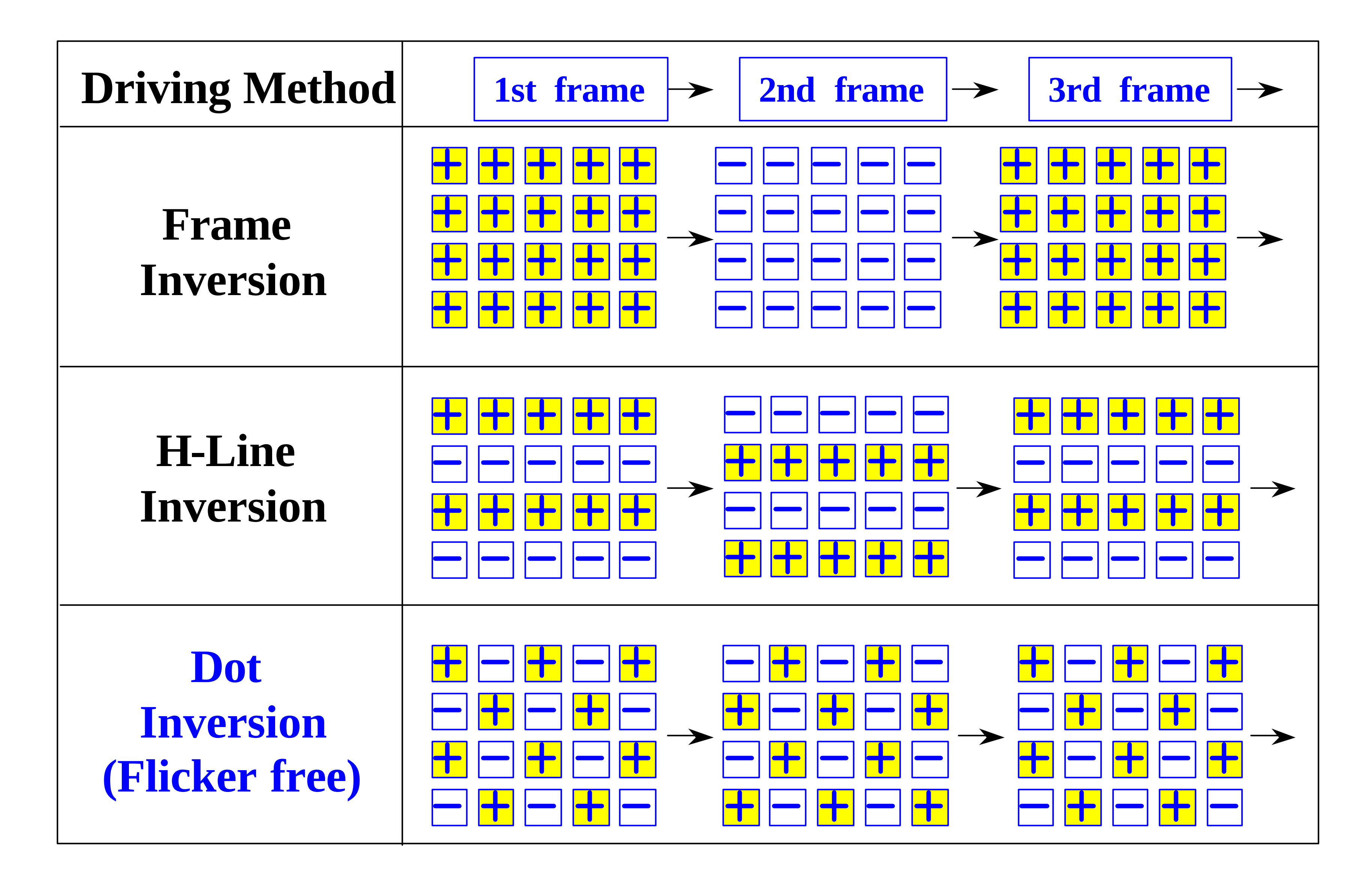


Figure 34. Polarity inversion driving methods

Gray Scale Generation

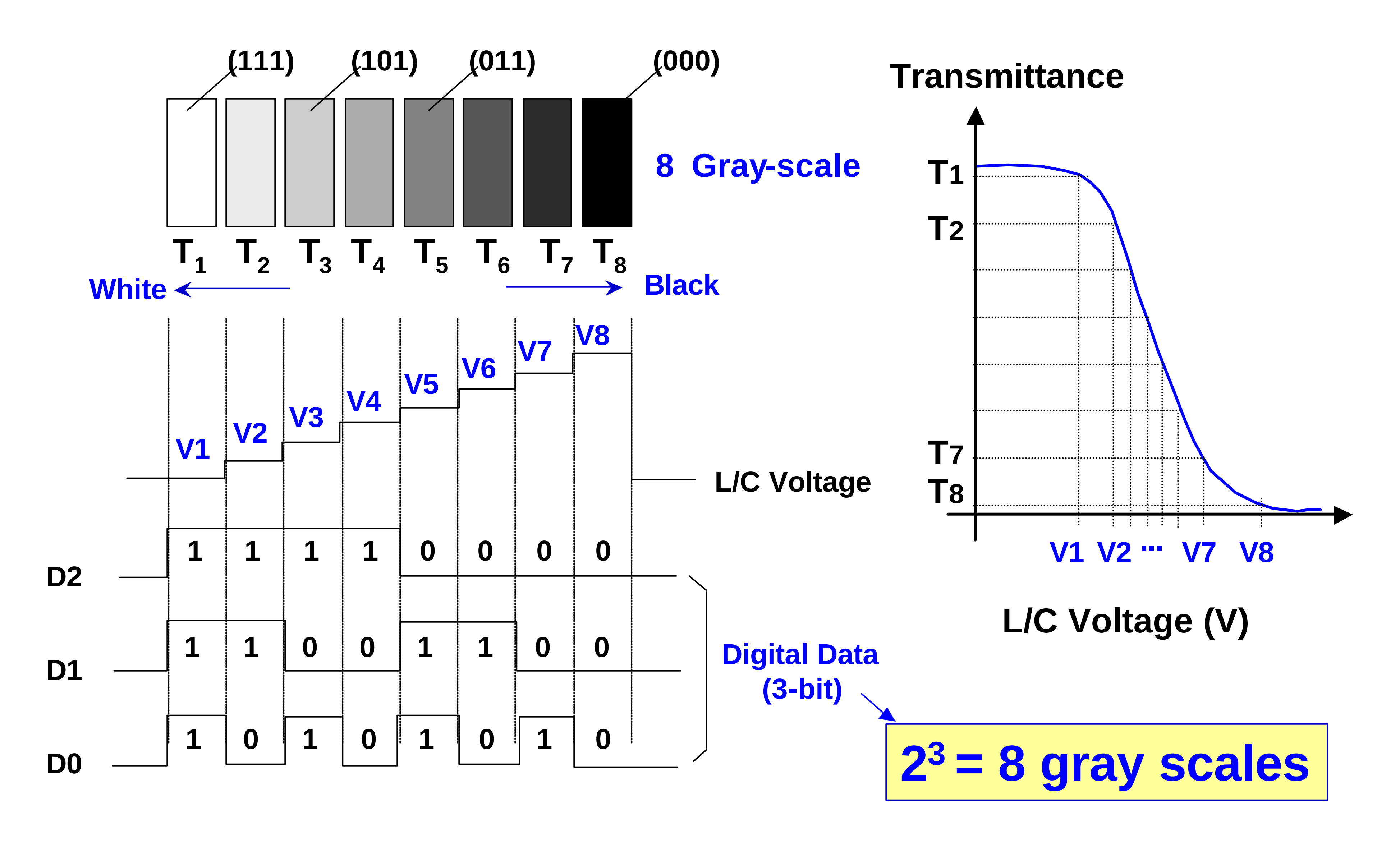
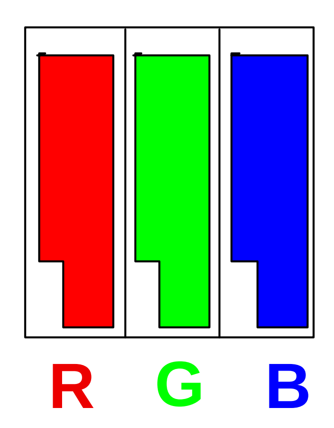


Figure 35. A gray-scale example of the 3-bit LDI

Total # of Colors

of Color = 2^n(R) x 2^n(G) x 2^n(B) = 2^{3n}

n= # of data bits of LDI chip



3 bit = 8-gray/RGB = 512 colors

4 bit = 16-gray/RGB = 4,096 colors

✓6 bit = 64-gray/RGB = 262,144 colors

8 bit = 256-gray/RGB = 16,777,216 colors

2^6=64
2^{18}=262,144

Analog IC = Continuous gray-scale = full color

Figure 36. Total number of LCD colors

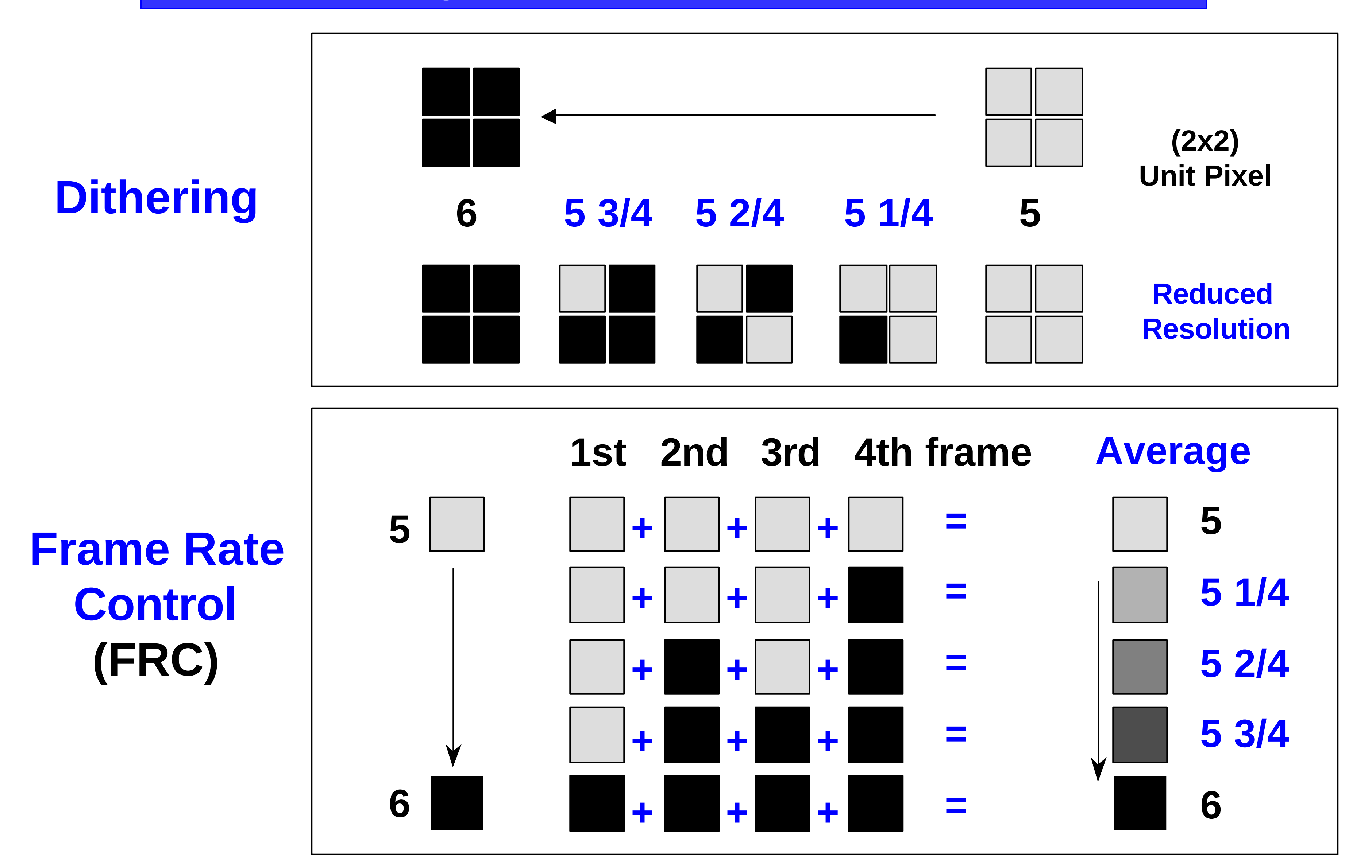


Figure 37. Dithering and frame rate control driving methods

Gray Scale with a Linear L/C Voltage

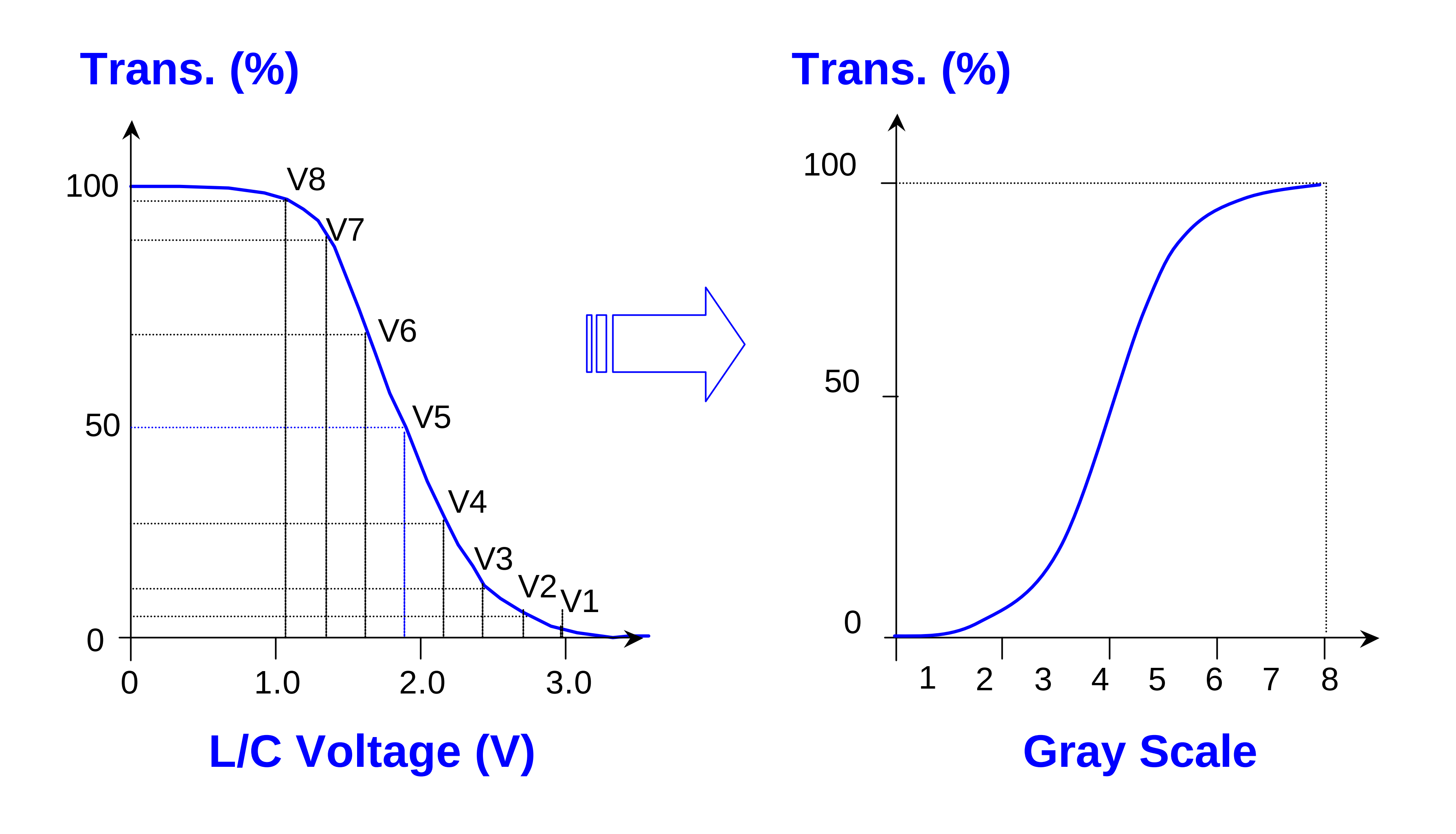


Figure 38. Gray-scale generation with a linear L/C voltage

Optimization of Gray Scale Curve

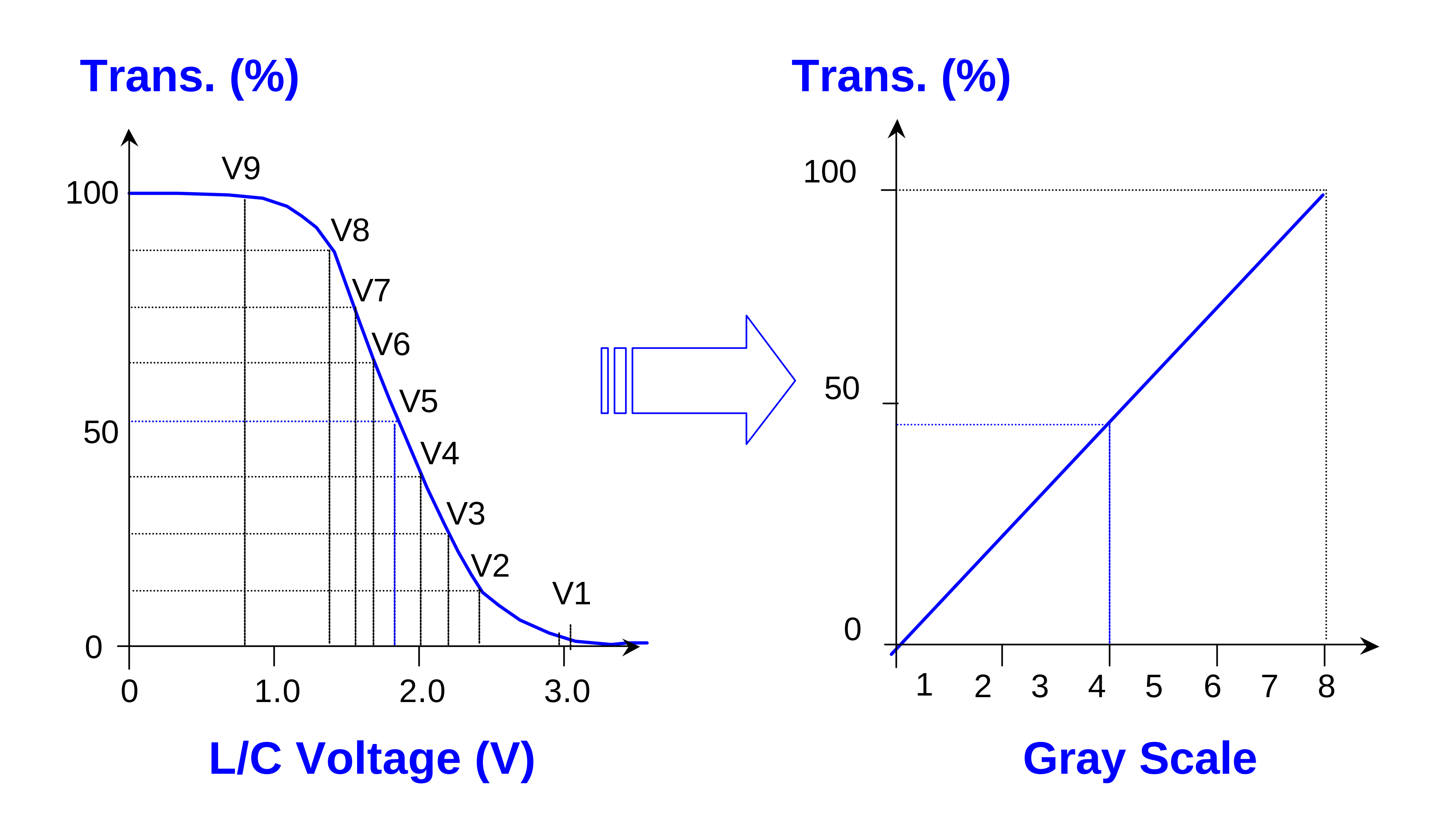


Figure 39. A gray-scale curve with an adjusted L/C voltage level

g -Correction of Gray Scale

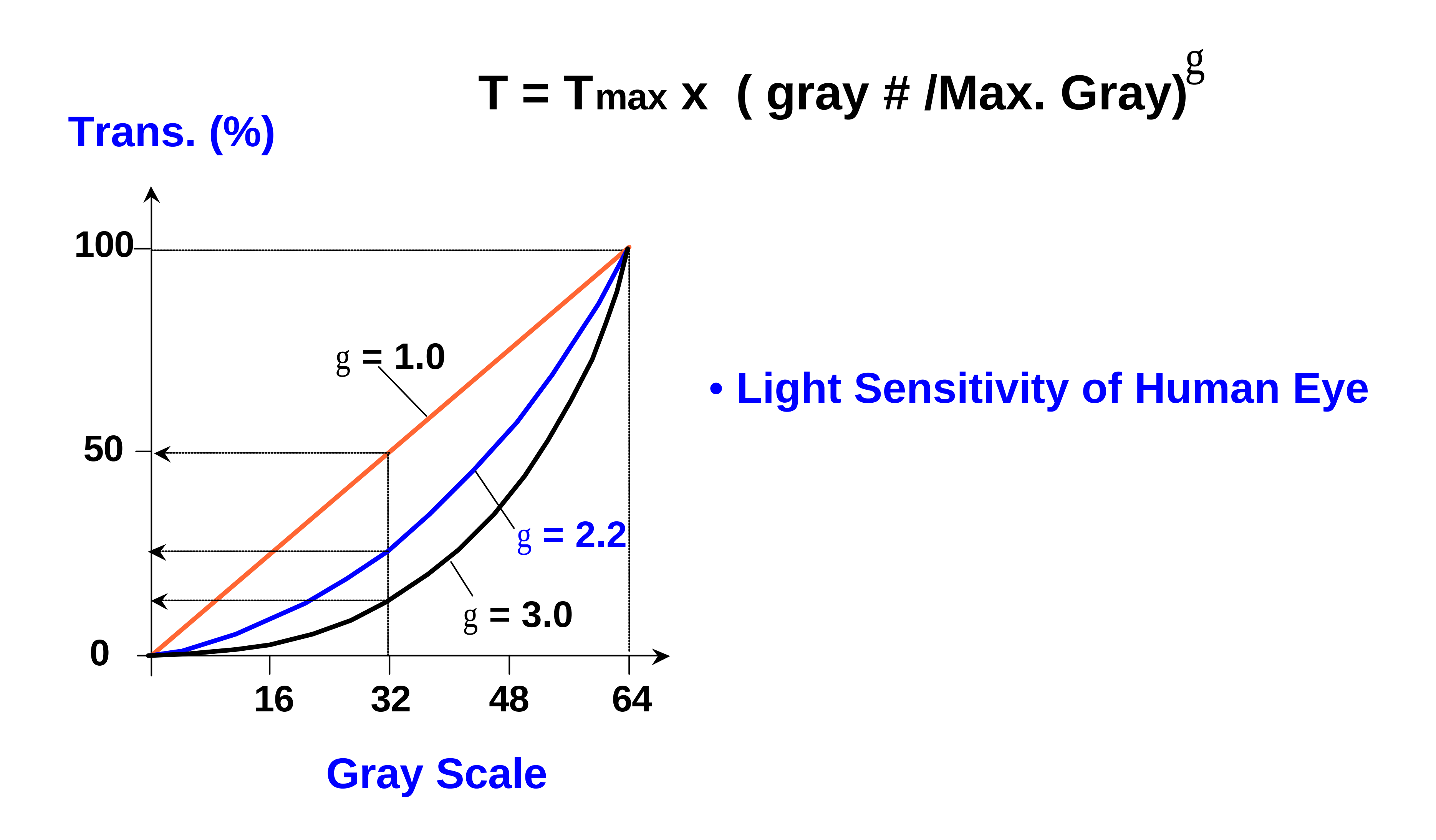


Figure 40. Gamma correction of the gray-scale curve

Color Generation

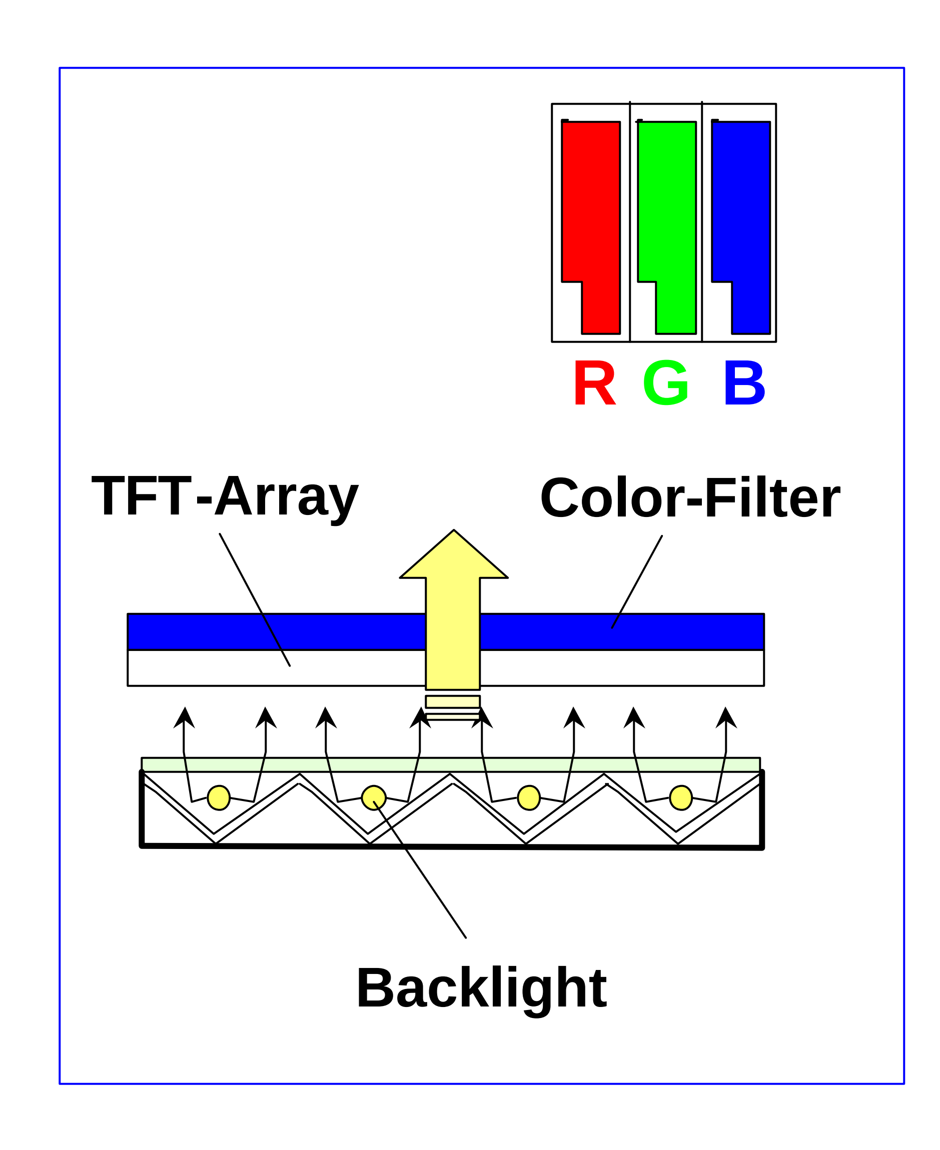


Figure 41. The color generation of the LCD

Pixel Size and Resolving Power of Human Eye

- 10.4 inch VGA : 0.110mm x 0.330mm (77dpi)
- 12.1 inch SVGA : 0.1025mm x 0.3075mm (83dpi)
- 15.0 inch XGA : 0.099mm x 0.297mm (117dpi)
- 17.0 inch SXGA : 0.090mm x 0.270mm (94dpi)
- 21.3 inch UXGA : 0.090mm x 0.270mm (94dpi)

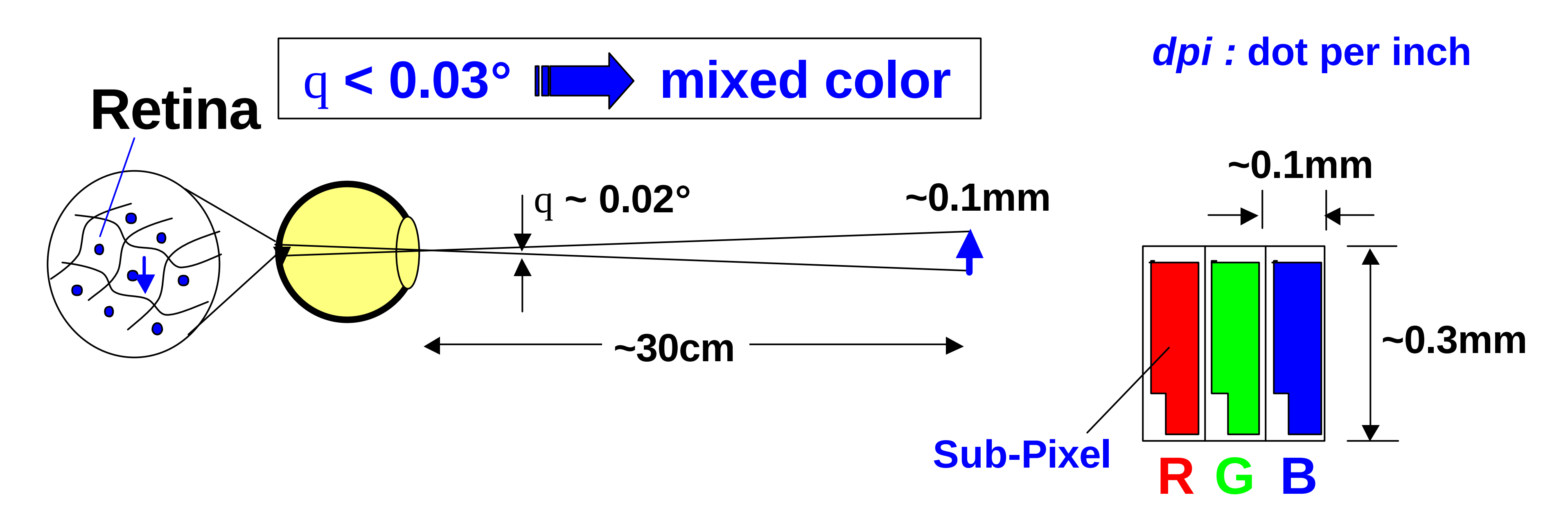
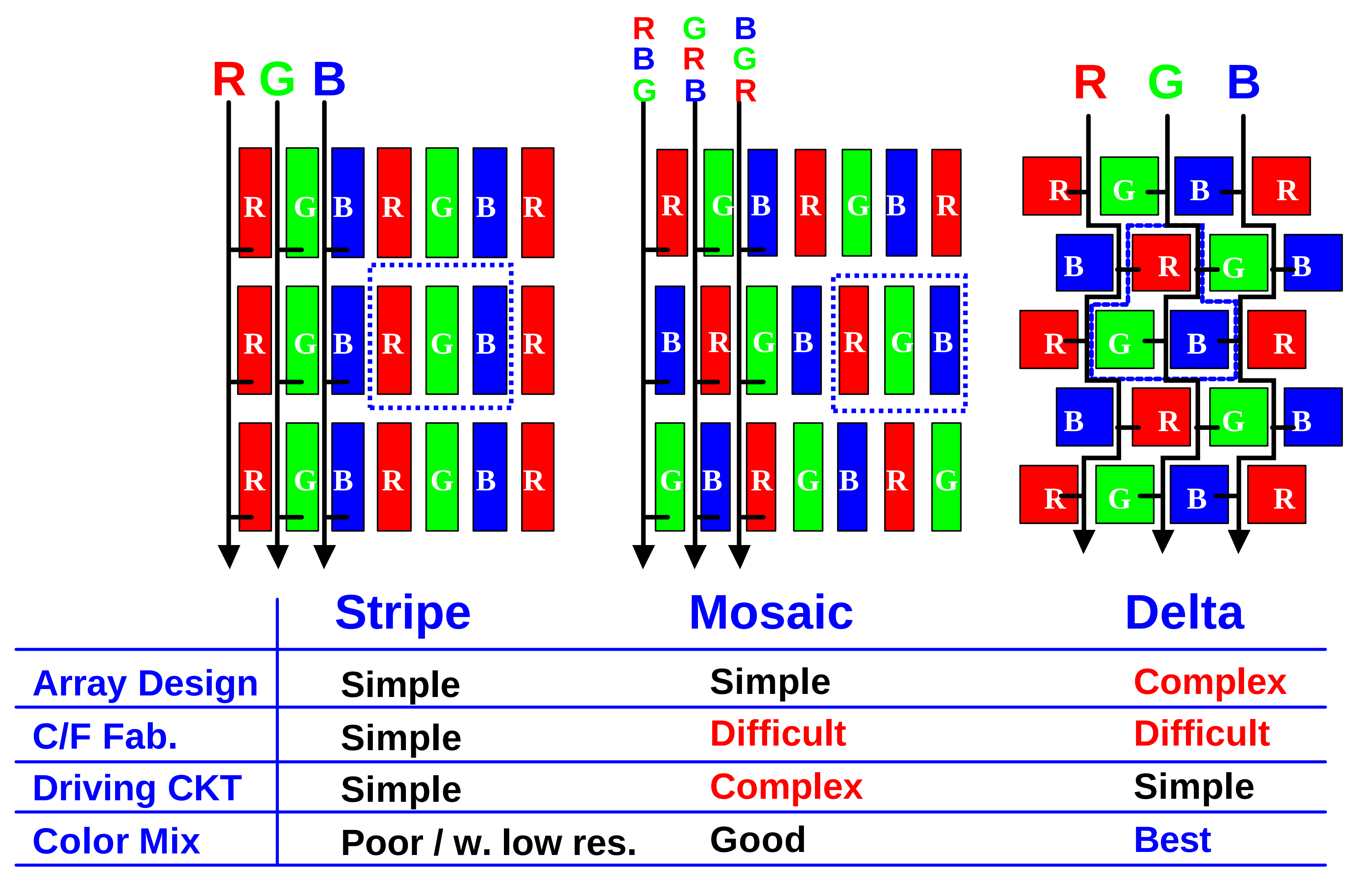


Figure 42. Color mix of RGB sub-pixel in the LCD panel

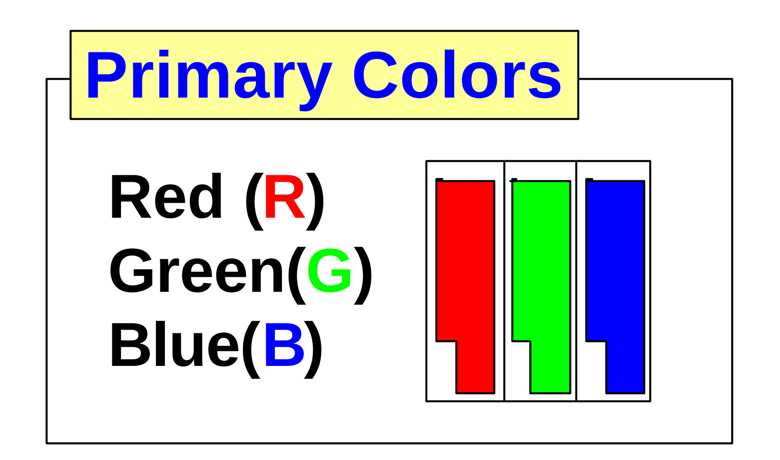
Arrangement of RGB



	Stripe	Mosaic	Delta
Array Design	Simple	Simple	Complex
C/F Fab.	Simple	Difficult	Difficult
Driving CKT	Simple	Complex	Simple
Color Mix	Poor / w. low res.	Good	Best

Figure 43. Arrangement of the RGB color-filter

Representation of Color



Color Coordinates

A color = rR + gG + bB

- $r = R/(R + G + B)$
- $g = G/(R + G + B)$
- $b = B/(R + G + B)$

with $r + g + b = 1$

B
b
(r, g, b)
g
G
r
R

Y
(x, y)
X

Figure 44. The color coordinates

CIE Color Coordinates

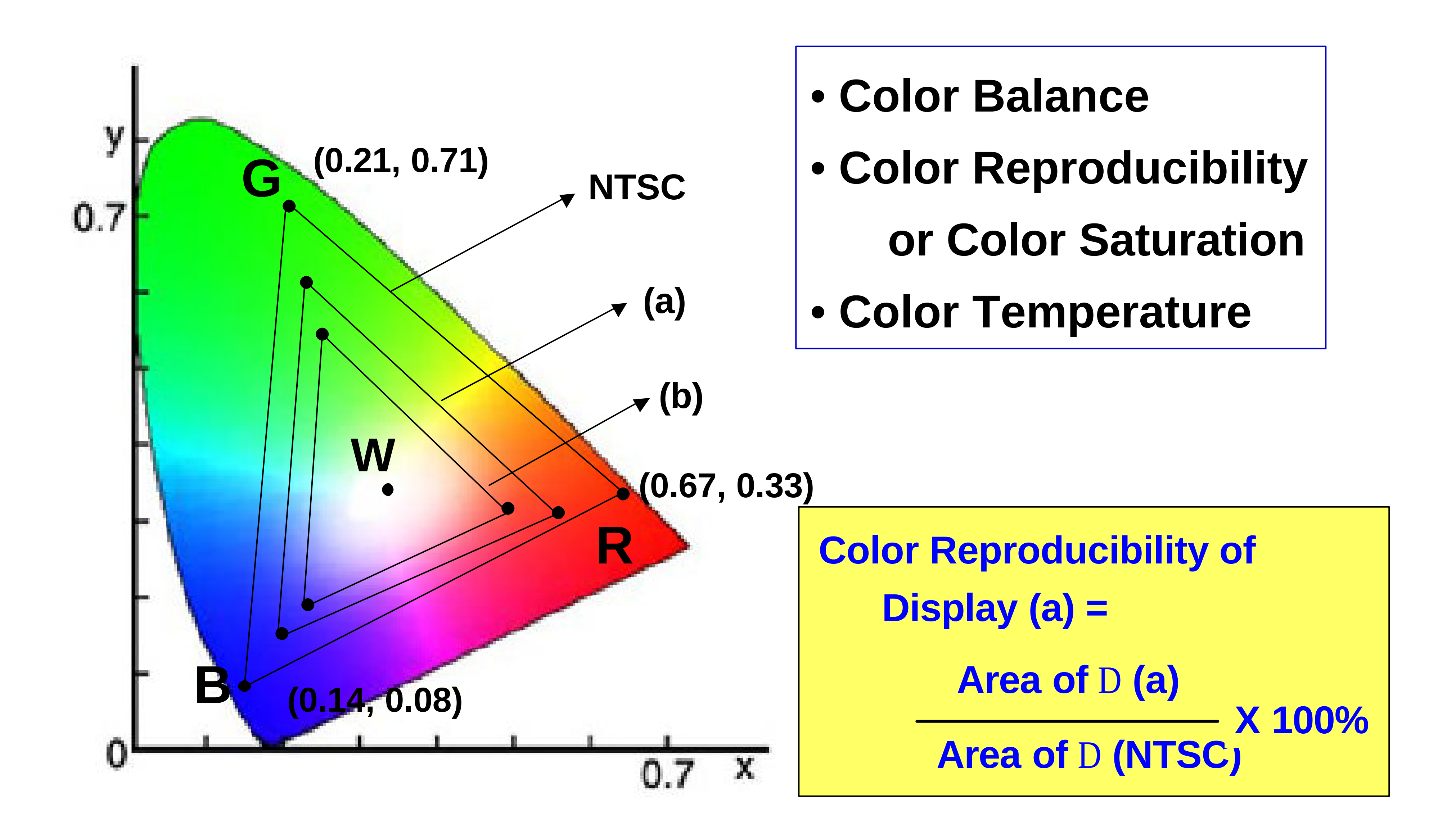


Figure 45. The CIE color coordinates